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ABSTRACT

This report describes four individualized programs which simulate physical experiments in force and motion, graph and data collected by individual students, and provide feedback to each student relative to his generalizations. An overview of the unit is provided, descriptions of the unit and accessory materials are presented, sample runs of the four programs are included, and instructional objectives are listed. Instructions given the students concerning procedures for running the programs, instructions for the teachers in regard to use of the programs, and evaluation instruments are included. One section of the report describes a study which evaluated the classroom use of these computer-based simulation programs. Finally, the program and file listings for each of the four programs, and non-computer simulation problem sheets are provided.

(DT)

Technical Report Series

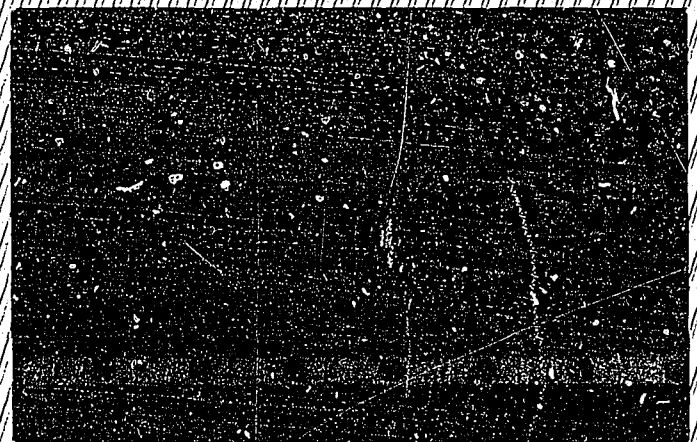
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SCIENCE EDUCATION CENTER

The University of Iowa

July 1974

technical report 1

Newton's Law: A Computer-Based
Simulation for Introductory Physics

by

Vincent N. Lunetta

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NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

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NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

UNIT OVERVIEW

technical report 1

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

PURPOSE

These four individualized programs simulate physical experiments in force and motion, graph the unique data collected by individual students, and provide feedback to each student relative to his generalizations. Film loops are available to improve the realism of each simulation.

ACCESS INSTRUCTIONS

Get-FORCEA
RUN

(Instructions for accessing successive programs are included within the first program of the series)

DESCRIPTION

These programs introduce Newton's Second Law through simulated laboratory experiences, and the Newton and Kilogram are defined. In using the programs, students improve their ability to make generalizations from graphed data and they will improve their understanding of motion and the property of inertia (Newton's First Law). The simulated experiments parallel a series of fundamental, inductive experiments developed by the Physical Science committee. The experiments are basic, yet to set up and adjust the real apparatus is a very time consuming process. This laboratory simulation is not designed to replace all first-hand experience with materials; however, the learning process can become more effective and efficient if appropriate laboratory work is supplemented with individualized, simulated experiments.

In each of the four programs the student must specify the variables for the particular experiment, e.g., the amount of force to be applied and the mass of the cart, in response to specific questions from the computer. The computer acts as "lab partner" and graphs the data: it then asks numerous questions about the regularities which are present. For example, the student has to determine acceleration from a graph of velocity vs. time in a couple of places.

If the student responds incorrectly, he is given assistance, and if he fails to grasp the concept after help has been provided more than once by the computer, he is instructed to see his teacher before proceeding; the program is then automatically terminated. Each completed simulation ends by instructing the student to list the sources of experimental error as he envisions them and to state the conclusions which can be drawn from the experiment. He is encouraged to pursue the investigation further at home or in the lab.

SUGGESTIONS FOR TEACHERS

This simulated experiment series is most appropriately utilized after linear motion and the property of inertia have been discussed but prior to introducing Newton's Second Law. Since students will spend approximately 30 minutes on each of the four programs, scheduling is critical when large numbers of students are involved. If multiple terminals are not available, other materials such as vectors and circular motion may be discussed in class while students progress through the simulated experiments on their own time.

To insure that students complete the series of programs, teachers should ask them that they turn in completed programs or that they include them in their laboratory notebooks. When a student reports to his teacher because his program was terminated early and he needs additional help, he should bring the computer output with him for review with his teacher. The concept causing the difficulty will be apparent in the closing lines of the program output.

1
Physical Science Study Committee, PHYSICS LABORATORY GUIDE, 2nd Edition
Heath 1965, 35-37

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

DESCRIPTIONS OF THE UNIT AND MATERIALS

technical report 1

Description of the Force and Motion Unit

The series of simulations produced in this study parallel the fundamental, inductive experiments developed by the Physical Science Study Committee (PSSC) through which students generalize Newton's Second Law.¹ General objectives of the Force and Motion Unit for experimental and control groups are:

A. To provide the student with a detailed understanding of Newton's Second Law;

B. To help the student develop graphical skills and an ability to interpret graphed data;

C. To help the student develop inquiry skills.

A more detailed list of specific objectives for the unit stated in behavioral terms is included in a subsequent section of this report.

Film Loops. The simulated investigations begin as the student views a film loop showing a jet plane during take-off. The film loop places the student in the role of experimenter, and through over-printing he is asked questions which cause him to consider the variables affecting the acceleration of the plane. The film fades from the airplane to a laboratory environment wherein the student is shown how to measure the effects of variables upon the acceleration of a dynamics cart. After viewing a person working with the apparatus, students acquire simulated data that they must analyze. After their analysis of the data, they move through successive viewings of film loops and interactions with the simulated experiments.

1 Physical Science Study Committee. Physics Laboratory Guide. Englewood, N.J.: D.C. Heath and Co., 1965, p. 35-37.

Programs. The simulations are broken into four major components, each developing one major idea as depicted in Figure 1. Program #1 (FORCEA) develops the concept that the velocity of an object changes at a constant rate when a constant force is applied, i.e., a constant force produces a constant acceleration. It also introduces the notion that the acceleration of a body is in some way inversely related to its mass. Program #2 (FORCEB) develops the idea that the acceleration of an object is directly related to the applied force. Program #3 (FORCEC) develops the idea that acceleration is inversely proportional to mass when the applied force is held constant. Program #4 (FORCED) synthesizes these concepts and develops Newton's Second Law from them; it also introduces the newton as the unit of force in the MKS system. Each program concludes with problems reviewing the concepts developed in the unit up to that point. Also, the student is asked to list the sources of experimental error as he envisions them and to state the conclusions which can be drawn from each investigation. He is encouraged to pursue each investigation further at home or in the laboratory.

Students interact with the computer through remote terminals using natural language messages to get unique data they are to analyze. Each computer program begins with a short question to assess whether or not the student has attained the competencies necessary to enter that phase of the unit. If he does not meet the entrance competency required in programs #2, #3, and #4, he is given a second chance to do so without any assistance. If he responds incorrectly the second time, he is told to review the previous program. If the computer determines that he does not meet the entrance competency at the beginning of program #1, he is given

Entry Concept:

Objects have constant velocity
when no net force acts upon them.

Program #1:

Constant force causes velocity
to change at a constant rate.

Determine acceleration from
velocity versus time graph.

Program #2:

Acceleration is directly
proportional to force.

$$A \propto F$$

Program #3:

Acceleration is inversely
proportional to mass

$$A \propto 1/M$$

Program #4:

$$F = MA$$

Newton introduced as force
unit in the MKS system.

Figure 1. Sequence of Major Concepts in the Instructional Unit

assistance by means of typed messages. If he fails to respond correctly in three attempts, he is told to review certain materials before returning to the computer terminal.

After the student enters a particular program, the computer plays the role of the student's lab partner in a dialog mode. It asks questions which allow the student to specify the independent variables in the investigation such as the amount of force to be applied and the mass of the cart, and it generates unique data for the dependent variable "very similar to that obtained by experimenters using the real apparatus shown in the film loop." In data collection, the computer types out statements such as: "You make the simulated run with the cart applying a force of XXX (specified previously by the student), then I'll analyze the ticker tape, make a data table, and plot a graph of velocity versus time..."

The computer organizes and plots the data many times faster than the student can, thus allowing him to focus on the regularities apparent in the data instead of the algebraic manipulations necessary to graph the data. An even more important aspect of these dialogs are the questions the computer asks the student concerning generalizations which should be apparent in the data. At some points the student is asked to determine acceleration from a velocity versus time graph (slope). At another point he must note that a curve does not pass through the origin, and he is asked to explain why it does not do so.

Typed below is a short extract from program #2 which conveys the nature of the interactive dialog concerning graphed data:²

NOTE THAT THE GRAPH DOES NOT PASS THROUGH THE ORIGIN. APPARENTLY THE CART DOES NOT ACCELERATE WHEN WE APPLY A SMALL POSITIVE FORCE. WHAT COULD CAUSE THIS?

?FRICTION

THERE IS FRICTION BETWEEN THE CART AND THE FLOOR WHICH OPPOSES THE FORCE WE APPLY. STUDY THE GRAPH AND DETERMINE FROM IT THE FORCE OF FRICTION (IN LOOPS).
?.5

FINE! THE FORCE OF FRICTION IS REPRESENTED BY THE INTERCEPT OF THE GRAPH WITH THE FORCE AXIS.

HAD WE USED A CART WITH GREATER FRICTION THAN IN OUR EXPERIMENT WOULD THIS INTERCEPT BE TO THE RIGHT OR LEFT OF ITS PRESENT LOCATION?

?RIGHT

CORRECT! NEXT, I'M GOING TO TAKE THE DATA WE COLLECTED AND PLOT THE RESULTANT FORCE ACTING ON THE CART, INSTEAD OF THE FORCE YOU APPLIED IN EACH RUN. (THE RESULTANT OR NET FORCE IS THE FORCE YOU APPLIED MINUS THE FORCE OF FRICTION.) TYPE IN THE POINT WHERE YOU THINK THE NEW PLOT WILL INTERSECT THE FORCE AXIS.

?0

RIGHT! HERE'S THE NEW GRAPH:

For brevity only correct responses have been shown. Had a response been incorrect, a discussion of the particular item would have appeared, followed by further questions on the same point. If the student exceeds a certain error rate, he is told to consult with his teacher before continuing the program. A sample error branching sequence is shown diagrammatically in Figure 2. The dashed line in the Figure indicates that after providing help the teacher has the option of sending the student on to the next instructional sequence or returning him to the same instructional sequence in which he encountered difficulty. This particular program

2 Question marks at the left edge of a line are followed by the student's response.

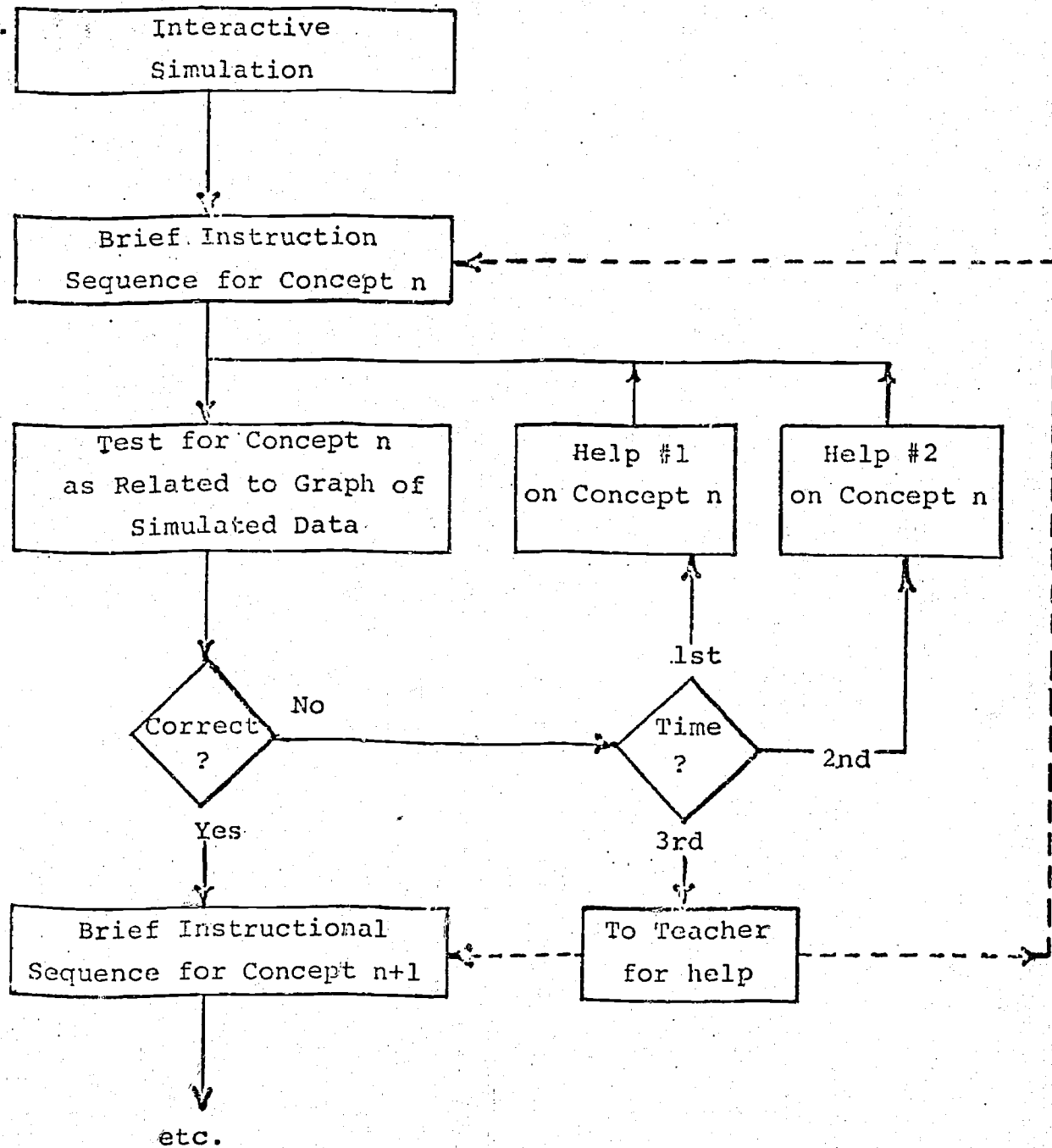


Figure 2. Sample Branching Sequence

segment extracted from program #2 is followed by the plotting of a new graph, a brief discussion of that graph, and a dialog which asks the student to write an equation to fit the graph. The sample computer dialog runs included in this report should be reviewed individually for a more thorough overview of the interactive simulations.

Simulated Data and Problem Sheets. Data and problem sheets providing information very similar to that in the computer programs are included in the final section of this report. They are designed for use by students who do not have access to an appropriate computer facility. Each data and problem sheet reviews briefly the objectives of the particular investigation and then provides data "the experimenters gathered... from a careful analysis of the ticker tape pulled by the cart." Each student is asked to graph the data and discuss specific questions relating to the graphs on an "investigation work sheet."

Unit Development

The particular concepts taught in this instructional unit were selected for several reasons. They are fundamental in mechanics, they are readily amenable to graphical display as linear relationships, and the author has observed that few physics teachers have students do laboratory work in the area. Initial program writing was done in English language. During the lesson writing, main programs were completed before error loops were written. (Error loops provide help following the entry of an incorrect student response). The completed programs were then coded in BASIC. Certain other computer languages

would have expedited program coding, but the BASIC language was the only language available to the author's students at that time, and it did not excessively constrain his initial objectives. In order to remain within a 5000 word core, each program in the series references a file in which messages are stored that do not contain variable quantities.

The lessons were altered in minor ways during encoding. Later they were revised based upon feedback from a small number of students who used the materials prior to widespread use of the programs.

The simulated data and problem sheets were prepared from the computer lessons after the computer lessons had been revised. Data appearing on these sheets were similar to that which is obtained by computer students, and the outline of the sheets parallels that of the computer programs. Questions and problems included in the computer programs are included on the simulated data and problem sheets. Correct answers are included for some of the problems, but most often the student is not provided with correct responses on the sheets. Feedback regarding the accuracy of his responses, if he is to get it, will come from other students, his teacher, or the graphed data.

Scripts for the film loops were written and initial filming was conducted concurrently with the initial program writing. Filming was done in Super 8mm on Kodachrome II film. After commercial processing, film clips were spliced into final form, and they were then commercially reproduced and placed in cartridges. (Titling was accomplished by filming through plates of glass on which block letters had been placed,)

Classroom Implementation

Teachers who use the Force and Motion simulations may bring their students through preliminary materials in a variety of conventional ways (See Behavioral Objectives 1-4.) The students then progress individually at their own rates through the programs. Students normally schedule their programs outside of class time. Completed programs are to be submitted on certain dates which are specified in advance.

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

SAMPLE PROGRAM RUNS

technical report 1

GET-FORCE
 RUN
 FORCEA

WELCOME TO OUR SIMULATED PHYSICS LAB. THROUGH THIS SERIES OF PROGRAMS AND FILM LOOPS WE WILL INVESTIGATE HOW FORCE AFFECTS THE MOTION OF AN OBJECT.
 HAVE YOU WATCHED THE FILM LOOP FORCE & MOTION I?

USE ONLY NUMERALS AND CARE FOR ANSWERS

YES

ONE INSTRUCTION BEFORE WE BEGIN: WHEN YOU'RE ASKED TO TYPE IN NUMERICAL DATA, DO NOT TYPE THE UNITS OF THE ANSWER. FOR EXAMPLE, AN ANSWER OF 10 M/SEC SHOULD BE TYPED "10". EXPERIENCE TELLS US THAT WE MUST APPLY A FORCE TO CAUSE AN OBJECT TO MOVE. IN THIS SERIES OF SIMULATED EXPERIMENTS WE SHALL INVESTIGATE PHYSICAL VARIABLES WHICH AFFECT THE MOTION OF AN OBJECT. THE DATA WHICH WE WILL GENERATE WILL BE VERY SIMILAR TO THAT OBTAINED BY EXPERIMENTERS USING THE REAL APPARATUS SHOWN IN THE FILM LOOP. I WILL BE YOUR LAB PARTNER.

BEFORE WE CONTINUE, YOU SHOULD BE FAMILIAR WITH THE PROPERTY OF INERTIA WHICH WAS DESCRIBED BY GALILEO AND NEWTON.

IF A ROCK IS TRAVELLING THROUGH SPACE AT 100 M/SEC AND THERE ARE NO FORCES ACTING ON IT, WHAT WILL BE ITS SPEED (IN M/SEC) 5 SEC. LATER?
 1100

CORRECT! DUE TO THE PROPERTY OF INERTIA (SOMETIMES CALLED NEWTON'S 1ST LAW) AN OBJECT'S VELOCITY WILL BE CONSTANT UNTIL AN UNBALANCED FORCE IS APPLIED. YET, IN WHAT WAY WILL AN UNBALANCED FORCE CAUSE THE VELOCITY TO CHANGE?

IN THIS FIRST EXPERIMENT WE SHALL INVESTIGATE HOW AN OBJECT'S VELOCITY CHANGES WHEN WE APPLY A CONSTANT FORCE. WE SHALL APPLY A CONSTANT FORCE TO THE CART BY KEEPING ONE LOOP OF RUBBER STRETCHED A CONSTANT LENGTH. (WE CAN STRETCH OUR LOOP TO ANY LENGTH BETWEEN 50CM AND 100CM.)

TYPE TELLN THE AMOUNT OF STRETCH IN CM WHICH YOU INTEND TO APPLY DURING THE RUNS THROUGHOUT THIS EXPERIMENT.

250

YOU HAVE THE SIMULATED RUN WITH THE CART APPLYING A FORCE OF 50 CM. THEN I'LL ANALYZE THE TICKER TAPE, MAKE A DATA TABLE, AND PLOT A GRAPH OF VELOCITY VERSUS TIME.

NOW HOW MANY TICKETS SHALL WE PLACE ON THE CART FOR A LOAD IN THIS RUN?

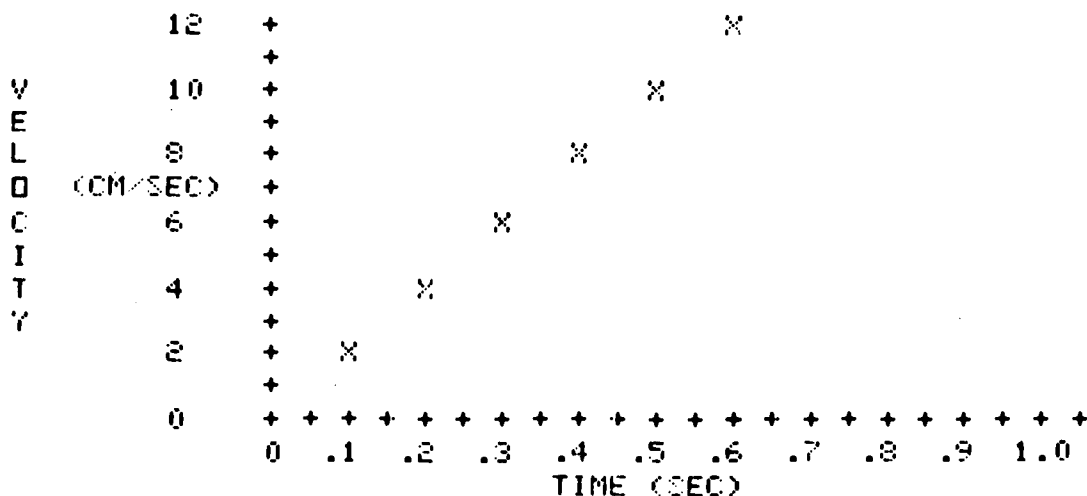
21

I'VE GOT TWO TICKETS FOR YOU --- AND THERE YOU GO PUSHING THE CART DOWN THE RAIL, RIGHT-WAYED TO A STOP!! ??

HERE IS A DATA TABLE I'VE MADE FROM THE TICKER TAPE PULLED BY THE
CAPT IN THIS RUN:

TIME (SEC)	VELOCITY (CM/SEC)	LOAD = 1	BRICKS	FORCE = 50	CM
.1	2				
.2	4				
.3	6				
.4	8				
.5	10				
.6	12				
.7	14.				
.8	16				
.9	18.				
1	20				

HERE IS A GRAPH OF THE DATA:



[LOAD = 1 BRICKS FORCE = 50 CM]

STUDY THE DATA AND GRAPH. CAN YOU OBSERVE ANY REGULARITIES?
YES!

PLEASE TYPE YES OR NO

STUDY THE DATA AND GRAPH. CAN YOU OBSERVE ANY REGULARITIES?
YES

WHAT KIND OF RELATIONSHIP EXISTS BETWEEN VELOCITY AND TIME UNDER THESE CONDITIONS (DIRECT OR INVERSE)?
DIRECT

RIGHT: IN FACT, THERE APPEARS TO BE A LINEAR RELATIONSHIP BETWEEN VELOCITY AND TIME IF WE OVERLOOK THE SMALL IRREGULARITIES PROBABLY CAUSED BY ENVIRONMENTAL EFFECTS -- SUCH AS VARIATIONS IN THE FORCE APPLIED. THE CHANGE IN VELOCITY WAS PROPORTIONAL TO THE TIME INTERVAL DURING WHICH THE FORCE ACTED. WHEN HE APPLIED A CONSTANT FORCE TO THE CART THE VELOCITY INCREASED AT A CONSTANT RATE.

FROM YOUR STUDY OF MOTION YOU WILL RECALL THAT ACCELERATION IS THE RATE OF CHANGE OF VELOCITY. THE ACCELERATION OF AN OBJECT IS THEN THE SLOPE OF ITS VELOCITY v . TIME GRAPH. YOU SEE IN MATHS WE IN DO.

FROM THE OFFICE OF THE ATTORNEY GENERAL, STATE OF NEW YORK
ALBANY, NEW YORK, JANUARY 10, 1907.

THE CONSTANT FORCE WE APPLIED IN THIS RUN DID PRODUCE A CONSTANT ACCELERATION.

ANALYZE THE GRAPH AND DETERMINE THE ACCELERATION IN CM/SEC/SEC.
???

OK. OUR CONSTANT FORCE OF 50 CM CAUSED OUR CART TO HAVE A CONSTANT ACCELERATION OF 20 CM/SEC/SEC.

BUT IS THE ACCELERATION ALWAYS CONSTANT UNDER THE INFLUENCE OF A CONSTANT FORCE?

HOW WOULD THE DATA DIFFER IF WE HAD USED A DIFFERENT LOAD?

TO FIND OUT, LET'S CHANGE THE NUMBER OF BRICKS ON THE CART AND MAKE ANOTHER RUN APPLYING THE SAME FORCE OF 50 CM.

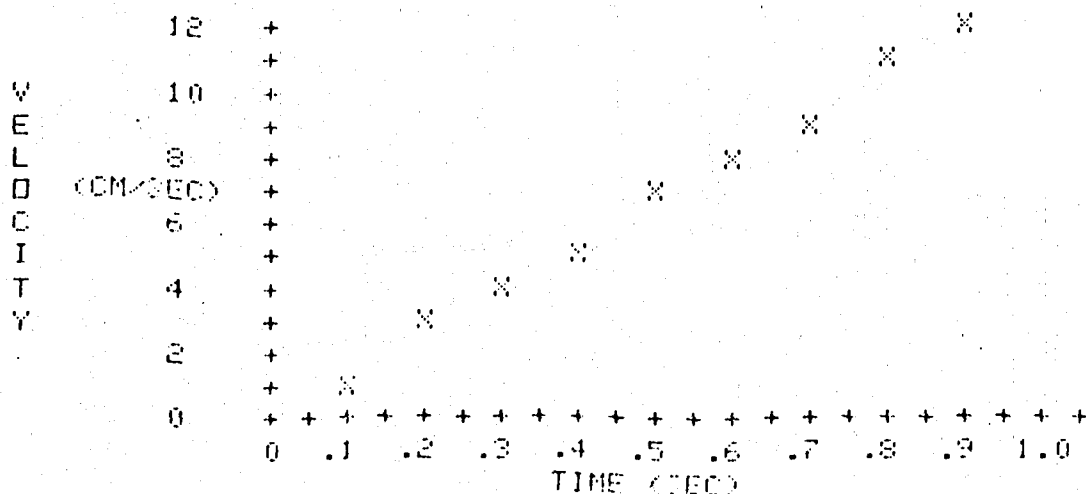
HOW MANY BRICKS SHALL WE PLACE ON THE CART FOR A LOAD IN THIS RUN?
??

I'VE GOT THE PUZZER ON: --- AND THERE YOU GO PUSHING THE CART DOWN THE HALL FLEET-FOOTED AS A DEER!! ??

HERE IS A DATA TABLE I'VE MADE FROM THE TICKER TAPE PULLED BY THE CART IN THIS RUN:

TIME (SEC)	VELOCITY (CM/SEC)	LOAD = 2	BRICKS	FORCE = 50	CM
.1	1.33				
.2	2.66				
.3	3.99				
.4	5.32				
.5	6.65				
.6	7.98				
.7	9.31				
.8	10.64				
.9	11.97				
1	13.3				

HERE IS A GRAPH OF THE DATA:



LOAD = 2 BRICKS FORCE = 50 CM

STUDY THE DATA AND GRAPH. CAN YOU DETERMINE A FEW THINGS?

THE CONSTANT FORCE WE APPLIED IN THIS RUN DID PRODUCE A CONSTANT ACCELERATION.
ANALYZE THE GRAPH AND DETERMINE THE ACCELERATION IN CM/SEC/SEC.
?13.3

OK. OUR CONSTANT FORCE OF 50 CM CAUSED OUR CART TO HAVE A CONSTANT ACCELERATION OF 13.3 CM/SEC/SEC.

AS YOU CAN SEE OUR DATA ALSO INDICATE THAT THE MASS OF THE CART DID AFFECT THE ACCELERATION.
WAS THE ACCELERATION GREATER OR SMALLER WHEN THE SMALLER MASS WAS ACCELERATED?
?GREATER

CORRECT: THE SMALLER MASS UNDERWENT A LARGER ACCELERATION. APPARENTLY THERE IS SOME KIND OF INVERSE RELATIONSHIP BETWEEN THE MASS OF AN OBJECT AND ITS ACCELERATION WHEN A CONSTANT FORCE IS APPLIED. WE WILL FURTHER INVESTIGATE THIS RELATIONSHIP IN THE THIRD EXPERIMENT IN THIS SERIES.
TO SUMMARIZE: WE CAN SEE FROM THE GRAPHS OF OUR DATA THAT WHEN A CONSTANT FORCE WAS APPLIED TO A CART WITH A PARTICULAR MASS THE ACCELERATION WAS CONSTANT.

NOW, LET'S TRY ONE LAST PROBLEM.
IF AN AIRPLANE'S ENGINES PRODUCE A NET FORCE WHICH IS CONSTANT AND WHICH ACCELERATES THE PLANE FROM 0 TO 100 M/SEC IN 20 SEC, WHAT WILL BE THE PLANE'S VELOCITY IN M/SEC AT THE END OF 40 SEC?
?200

RIGHT! AGAIN, A CONSTANT FORCE CAUSES A MASS TO HAVE A CONSTANT ACCELERATION.
BUT HOW WOULD THE ACCELERATION HAVE DIFFERED HAD WE APPLIED A DIFFERENT FORCE?--THIS QUESTION WILL FORM THE BASIS FOR THE NEXT EXPERIMENT IN THIS SERIES.

SINCE YOU HAVE BEEN STUDYING FORCE AND MOTION USING A SIMULATED EXPERIMENT, YOU HAVE NOT HAD TO COME WITH THE MANY SOURCES OF EXPERIMENTAL ERROR PRESENT IN THE ACTUAL APPARATUS. IF YOU WERE TO DO THE REAL EXPERIMENT YOU WOULD HAVE TO REDUCE SUCH ERROR BEFORE THE GENERALIZATIONS WE'VE SEEN COULD BE OBSERVED. REAL AS YOU WILL BE ABLE TO PURSUE THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB.
AFTER YOU'VE SIGNED OFF THE TECHNICAL ROLL OUT SEVERAL EXTRA INCHES OF FILM. ON THIS FILM LIST THE SOURCES OF EXPERIMENTAL ERROR AS YOU ENVISION THEM AND STATE THE MAJOR CONCLUSIONS YOU CAN DRAW FROM THE EXPERIMENT.
INCLUDE THIS REPORT IN YOUR PHYSICS PORTFOLIO. AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM LOOP (FORCE & MOTION II) AND THEN RUN THE COPY.

TO SIGN OFF THE TECHNICAL TYPE (BYR) AND PRESS THE RETURN KEY

10000

RUN
FORCE8

WELCOME AGAIN TO OUR SIMULATED PHYSICS LAB. IN THIS SECOND EXPERIMENT OF THE SERIES WE WILL INVESTIGATE HOW FORCES AFFECT THE ACCELERATION OF AN OBJECT. HAVE YOU COMPLETED FORCE8 & WATCHED THE FILM LOOP "FORCE & MOTION II"?

?YES

IN OUR LAST EXPERIMENT WE OBSERVED THAT A CONSTANT FORCE GAVE OUR CART WHAT KIND OF ACCELERATION?

?CONSTANT

RIGHT! NOW TO STUDY HOW ACCELERATION VARIES WHEN THE APPLIED FORCE IS CHANGED WE'LL HOLD ALL OTHER VARIABLES (SUCH AS MASS) CONSTANT. HOW MANY BRICKS SHALL WE PLACE ON THE CART THROUGHOUT THIS EXPERIMENT?

?4

AS YOU OBSERVED IN THE FILM, WE CAN VARY THE FORCE WE APPLY BY USING DIFFERENT NUMBERS OF RUBBER LOOPS STRETCHED A CONSTANT LENGTH. I SUGGEST 50 CM FOR ALL LOOPS IN THIS EXPERIMENT YOU SPECIFY THE FORCE YOU'LL APPLY IN EACH TRIAL AND MAKE THE SIMULATED RUN. THEN I'LL DETERMINE ACCELERATION FROM THE TICKER TAPE AND PLOT A GRAPH OF ACCELERATION V. FORCE WHEN WE HAVE ENOUGH DATA.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?

?2.5

WE DON'T HAVE ANY PARTIAL LOOPS IN OUR LAB. TYPE IN A WHOLE NUMBER.

?2

THE ACCELERATION IN THIS RUN WAS: 9.6 CM/SEC/SEC.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?

?4

THE ACCELERATION IN THIS RUN WAS: 28.8 CM/SEC/SEC.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?

?6

THE ACCELERATION IN THIS RUN WAS: 48 CM/SEC/SEC.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?

?8

THE ACCELERATION IN THIS RUN WAS: 67.2 CM/SEC/SEC.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?

?10

THE ACCELERATION IN THIS RUN WAS: 86.4 CM/SEC/SEC.

IF YOU'D LIKE TO MAKE ANOTHER RUN, TYPE "RUN"; IF YOU'D LIKE ME TO GRAPH A V. F. TYPE "PLOT".

?PLOT

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?
?1

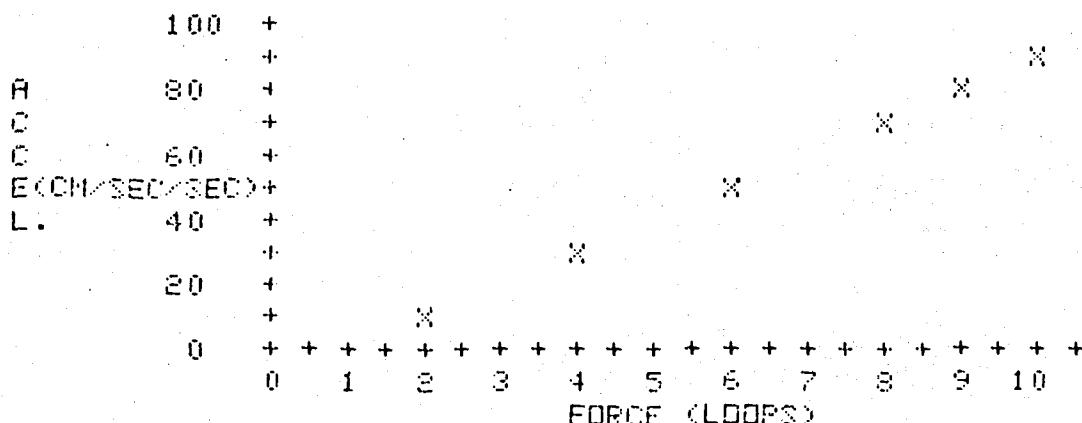
THE ACCELERATION IN THIS RUN WAS: 0 CM/SEC/SEC.

IF YOU'D LIKE TO MAKE ANOTHER RUN, TYPE 'RUN'; IF YOU'D LIKE ME
TO GRAPH A VS. F, TYPE 'PLOT'.
?RUN

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?
?9

THE ACCELERATION IN THIS RUN WAS: 76.8 CM/SEC/SEC.

IF YOU'D LIKE TO MAKE ANOTHER RUN, TYPE 'RUN'; IF YOU'D LIKE ME
TO GRAPH A VS. F, TYPE 'PLOT'.
?PLOT



CAN YOU OBSERVE ANY REGULARITIES IN THIS GRAPH?

?YES

WHAT KIND OF RELATIONSHIP EXISTS BETWEEN ACCELERATION AND FORCE
(DIRECT OR INVERSE)?

?DIRECT

RIGHT! IN FACT, THERE APPEARS TO BE A LINEAR RELATIONSHIP
BETWEEN FORCE AND ACCELERATION IF WE OVERLOOK THE IRREGULARITIES
PROBABLY CAUSED BY EXPERIMENTAL ERROR.

NOTE THAT THE GRAPH DOES NOT PASS THROUGH THE ORIGIN.
APPARENTLY THE CART DOES NOT ACCELERATE WHEN WE APPLY A
SMALL POSITIVE FORCE. WHAT COULD CAUSE THIS?

?FRICTION

THERE IS FRICTION BETWEEN THE CART AND THE FLOOR WHICH OPPOSES THE
FORCE WE APPLY. STUDY THE GRAPH & DETERMINE THE FORCE OF
FRICTION (IN LOOPS).

?1

FINE! THE FORCE OF FRICTION IS REPRESENTED BY THE INTERCEPT OF THE GRAPH WITH THE FORCE AXIS.

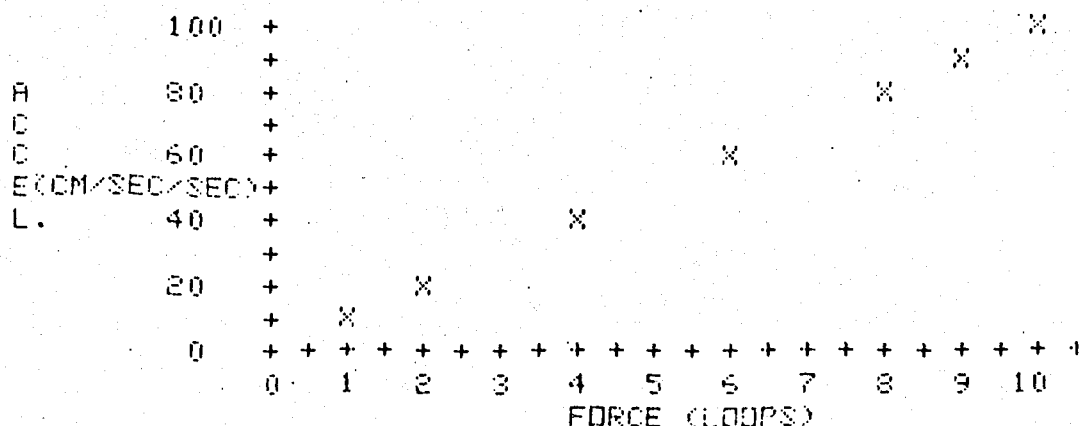
HAD WE USED A CART WITH GREATER FRICTION THAN IN OUR EXPERIMENT WOULD THIS INTERCEPT BE TO THE RIGHT OR LEFT OF ITS PRESENT LOCATION? (TYPE 'RIGHT' OR 'LEFT')
?RIGHT

CORRECT! NEXT, I'M GOING TO TAKE THE DATA WE COLLECTED AND PLOT THE RESULTANT FORCE ACTING ON THE CART, INSTEAD OF THE FORCE YOU APPLIED IN EACH RUN. (THE RESULTANT OR NET FORCE IS THE FORCE YOU APPLIED MINUS THE FORCE OF FRICTION.)

TYPE IN THE POINT WHERE YOU THINK THE NEW PLOT WILL INTERSECT THE FORCE AXIS.

?0

RIGHT! HERE'S THE NEW GRAPH:



AGAIN, WE SEE A LINEAR RELATIONSHIP BETWEEN FORCE AND ACCELERATION. NOTE THAT THOUGH THE INTERCEPT WITH THE FORCE AXIS HAS BEEN MOVED, THE SLOPE OF THE GRAPH HAS NOT CHANGED. FRICTIONAL FORCE DOES NOT APPEAR TO AFFECT THE SLOPE OF THE ACCEL. VS. FORCE GRAPH.

WRITE AN EQUATION TO FIT THIS GRAPH. USE 'A' TO REPRESENT ACCELERATION AND 'F' TO REPRESENT FORCE. USE 'K' TO REPRESENT THE SLOPE (DON'T BOTHER TO CALCULATE IT). BEGIN THE EQUATION: A= ...
?A=KF

RIGHT!--BUT WHAT FACTORS WILL CAUSE THE SLOPE TO CHANGE? WE'VE OBSERVED THAT FRICTION HAS NO EFFECT. WHAT OTHER VARIABLE MIGHT CAUSE THE SLOPE TO CHANGE?
?MASS

AS WE OBSERVED IN THE LAST EXPERIMENT, MASS HAS AN INVERSE RELATIONSHIP TO ACCELERATION WHEN A CONSTANT FORCE IS APPLIED. IN THE NEXT EXPERIMENT WE'LL CONDUCT A QUANTITATIVE STUDY OF THIS RELATIONSHIP.

TO SUMMARIZE, WE CAN GET FROM OUR DATA THAT ACCELERATION IS DIRECTLY PROPORTIONAL TO THE NET FORCE WHEN THE MASS REMAINS CONSTANT. THE EQUATION FOR THE RELATIONSHIP IS $a = F/m$. I SHOULD EMPHASIZE THAT F REPRESENTS THE NET OR RESULTANT FORCE; IT IS THE VECTOR SUM OF ALL FORCES ACTING ON THE OBJECT. NOW, TRY THIS PROBLEM:

A SPACE-SHIP IS ACCELERATING IN SPACE AT 10 m/sec^2 DUE TO THE FORCE PROVIDED BY ONE ROCKET ENGINE. SUDDENLY 2 MORE IDENTICAL ROCKETS ARE IGNITED PROVIDING THRUST IN THE SAME DIRECTION AS THE FIRST. WHAT ACCELERATION IN m/sec^2 DOES THE SHIP NOW EXPERIENCE?

730

GOOD! HERE'S ANOTHER PROBLEM FOR YOU TO TRY:
IN 10 SEC AN OBJECT ACCELERATES FROM REST TO A SPEED OF 300 cm/sec WHEN ACTED UPON BY A NET FORCE F . AT THE END OF THE 10 SEC INTERVAL F BECOMES ONE-THIRD ITS ORIGINAL STRENGTH. WHAT IS THE SPEED OF THE OBJECT AT THE END OF THE FIRST 20 SEC IN cm/sec ?

7400

CORRECT!

YOU HAVE NOW COMPLETED THIS SIMULATED EXPERIMENT. PERHAPS YOU WILL BE ABLE TO PURSUE THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB.

AFTER YOU'VE SIGNED OFF THE TERMINAL, ROLL OUT SEVERAL INCHES OF PAPER. ON IT LIST THE PURPOSE OF EXPERIMENTAL ERROR AS YOU OBSERVE THEM AND STATE THE MAJOR CONCLUSIONS YOU CAN DRAW FROM THE EXPERIMENT. INCLUDE THIS PAPER IN YOUR PHYSICS PORTFOLIO.
AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM LOOP (FORCE & MOTION III), THEN RUN 'FORCEC'.

TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY

DONE

RUN
FORCED

HELLO AGAIN. IN THIS THIRD PROGRAM OF THE SERIES WE WILL STUDY HOW A CONSTANT FORCE ACCELERATES DIFFERENT MASSES. HAVE YOU COMPLETED 'FORCED' AND THEN VIEWED FILM LOOP 'FORCE & MOTION III'?

??YES

IN THE FIRST EXPERIMENT OF THIS SERIES WE OBSERVED THAT CONSTANT FORCES CAUSE A BODY TO UNDERGO A CONSTANT ACCELERATION. IN THE LAST EXPERIMENT WE HELD THE MASS CONSTANT AND OBSERVED WHAT KIND OF RELATIONSHIP BETWEEN ACCELERATION AND FORCE?

?LINEAR

RIGHT. NOW TO STUDY HOW ACCELERATION VARIES WHEN THE OBJECT'S MASS IS CHANGED WE'LL TRY TO HOLD ALL OTHER VARIABLES CONSTANT. WE'LL APPLY THE SAME FORCE TO THE CART IN ALL RUNS BY KEEPING ONE LOOP OF RUBBER STRETCHED A CONSTANT LENGTH. (WE CAN STRETCH OUR LOOP BETWEEN 50 AND 100CM.)

TYPE BELOW THE AMOUNT OF STRETCH IN CM YOU WILL APPLY DURING THE RUNS THROUGHOUT THIS EXPERIMENT.

??5

WE CAN VARY THE CART'S MASS BY USING DIFFERENT NUMBERS OF IDENTICAL BRICKS FOR A LOAD. THE MASS OF THE EMPTY CART WE'LL USE HAS BEEN ADJUSTED TO EQUAL THE MASS OF ONE BRICK.

YOU SPECIFY THE NUMBER OF BRICKS YOU'LL USE FOR A LOAD IN EACH TRIAL AND MAKE THE SIMULATED RUN. THEN I'LL DETERMINE ACCELERATION FROM THE TICKER TAPE AND PLOT A GRAPH OF ACCELERATION V. MASS. REMEMBER, THE MASS YOU'RE ACCELERATING IS ONE BRICK LARGER THAN THE LOAD YOU SPECIFY SINCE THE CART HAS A MASS OF 1 BRICK.

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?

?0

YOU WILL FIND THAT IF YOUR CART HAS NO BRICKS ON IT AND YOU APPLY A FORCE OF 75 CM THE CART WILL TAKE OFF SO FAST YOU WON'T BE ABLE TO APPLY A CONSTANT FORCE. I SUGGEST AT LEAST 1 BRICK FOR A LOAD.

SO, AGAIN --

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?

?1

FOR YOUR TOTAL MASS OF 2 BRICKS, THE ACCELERATION WAS: 30 CM/SEC/SEC. [1/A= .033]

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?

?2

FOR YOUR TOTAL MASS OF 3 BRICKS, THE ACCELERATION WAS: 20 CM/SEC/SEC. [1/A= .05]

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?

?3

FOR YOUR TOTAL MASS OF 4 BRICKS, THE ACCELERATION

WAS: 15 CM/SEC/SEC. [1/A= .066]

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?

?4

FOR YOUR TOTAL MASS OF 5 BRICKS, THE ACCELERATION

WAS: 12 CM/SEC/SEC. [1/A= .083]

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?

?9

FOR YOUR TOTAL MASS OF 10 BRICKS, THE ACCELERATION

WAS: 6 CM/SEC/SEC. [1/A= .166]

IF YOU'D LIKE TO MAKE ANOTHER RUN TYPE 'RUN'; IF YOU'D LIKE ME TO GRAPH A VERSUS M TYPE 'PLOT'.

?7

YOU DIDN'T TYPE 'PLOT' OR 'RUN'. AGAIN, WHICH SHOULD WE DO?

?RUN

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?

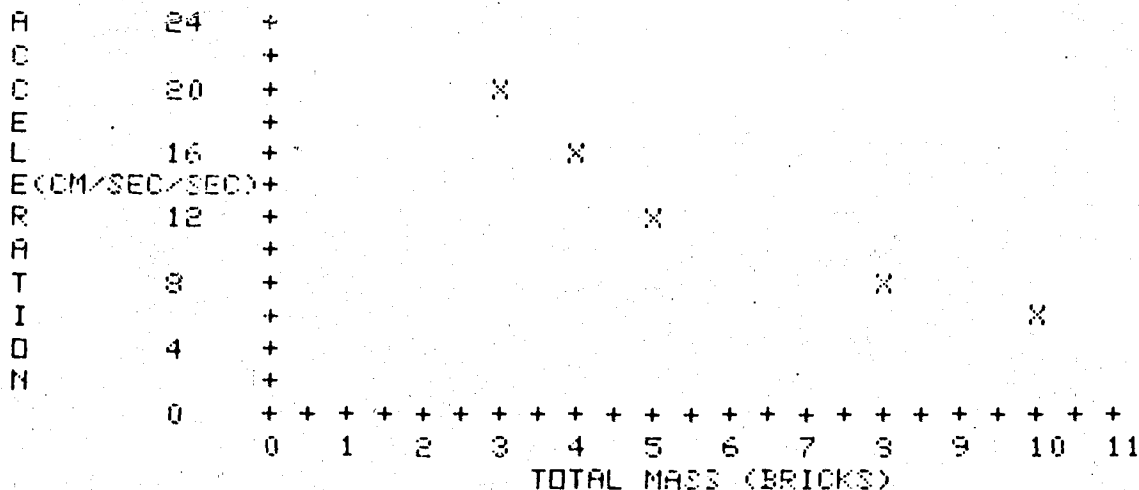
?7

FOR YOUR TOTAL MASS OF 8 BRICKS, THE ACCELERATION

WAS: 7.5 CM/SEC/SEC. [1/A= .133]

IF YOU'D LIKE TO MAKE ANOTHER RUN TYPE 'RUN'; IF YOU'D LIKE ME TO GRAPH A VERSUS M TYPE 'PLOT'.

?PLOT



STUDY THE GRAPH CAREFULLY. CAN YOU OBSERVE ANY REGULARITIES?

?YES

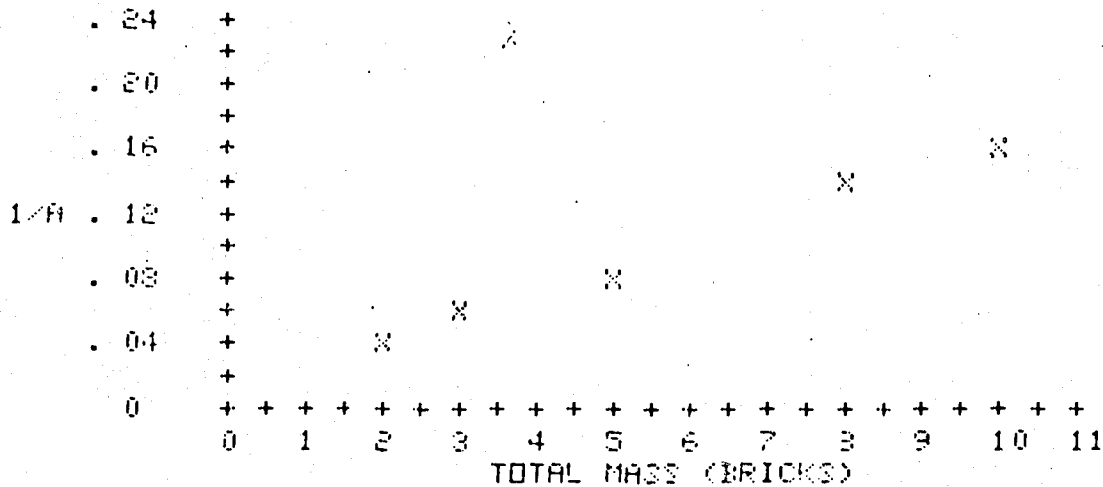
WHAT KIND OF RELATIONSHIP EXISTS BETWEEN ACCELERATION AND MASS (DIRECT OR INVERSE)?

?INVERSE

RIGHT! AS THE CART'S MASS GETS LARGER THE ACCELERATION GETS SMALLER UNDER THE INFLUENCE OF A CONSTANT FORCE.

OUR NEXT TASK IS TO FIND AN ALGEBRAIC EXPRESSION FOR THE RELATIONSHIP BETWEEN ACCELERATION AND MASS. A STUDY OF OUR GRAPH SUGGESTS THAT IT MIGHT BE A 1ST POWER INVERSE RELATIONSHIP, THAT IS: ACCEL. IS DIRECTLY PROPORTIONAL TO $1/\text{MASS}$, OR MASS IS DIRECTLY PROPORTIONAL TO $1/\text{ACCELERATION}$. TO CHECK OUT THIS PREDICTION I WILL PLOT A NEW GRAPH OF $1/A$ VERSUS MASS FOR EACH OF OUR TRIALS USING THE DATA WE COLLECTED.

HERE'S THE NEW GRAPH:



AWA! VERY INTERESTING.

THIS GRAPH DOES MAKE THE RELATIONSHIP MORE OBVIOUS. DO YOU SEE WHAT I MEAN?

YES

THE LINEAR GRAPH INDICATES A DIRECT RELATIONSHIP BETWEEN THE TWO VARIABLES WE'VE PLOTTED.

WRITE AN EQUATION TO FIT THIS GRAPH. DO NOT BOTHER TO CALCULATE THE SLOPE; INSTEAD REPRESENT THE SLOPE WITH THE CONSTANT 'K'.

BEGIN THE EQUATION: $1/A = \dots$

$1/A = KM$

RIGHT! THERE IS A DIRECT RELATIONSHIP BETWEEN $1/A$ AND MASS; K COULD OF COURSE BE REPLACED BY THE NUMERICAL VALUE FOR THE SLOPE OF THE LINE.

HERE IS A PROBLEM FOR YOU TO TRY USING YOUR GRAPH AND THE SIMULATED APPARATUS: A ROCK OF UNKNOWN MASS IS PLACED ON OUR UNLOADED CART. YOU MAKE A RUN WITH IT APPLYING THE SAME FORCE AS YOU DID IN THE OTHER RUNS. MY ANALYSIS OF THE TAPE INDICATES AN ACCELERATION OF 15.0 CM/SEC/SEC . WHAT IS THE TOTAL MASS OF ROCK AND CART (TO THE NEAREST 10TH BRICK)?

74

OK; THE MASS OF ROCK AND CART IS: 4 BRICKS.

WHAT IS THE MASS OF THE ROCK ALONE?

73

GOOD! THIS IS ONE METHOD WHICH CAN BE USED TO DETERMINE THE MASS OF AN OBJECT.

TO SUMMARIZE, WE CAN SEE FROM THE GRAPHS OF OUR DATA THAT THE ACCELERATION OF AN OBJECT IS INVERSELY PROPORTIONAL TO ITS INERTIAL MASS WHEN A CONSTANT FORCE IS APPLIED, AND THE EQUATION YOU WROTE FOR THE RELATIONSHIP IS: $1/A=KM$.

NOW TRY THIS PROBLEM:

A CAR HAS A MAXIMUM ACCELERATION OF 8 M/SEC/SEC. IF THE CAR TOWS ANOTHER CAR OF IDENTICAL MASS AND DESIGN, WHAT WILL BE THE MAXIMUM ACCEL. IN M/SEC/SEC?

?4

GOOD! NOW HERE'S ANOTHER PROBLEM:

MASS A ACCELERATES AT 80 FT/SEC/SEC AND MASS B ACCELERATES AT 20 FT/SEC/SEC WHEN IDENTICAL FORCES ARE APPLIED.

WHAT IS THE RATIO: MASS A/MASS B?

?4/1

NO. THE PROBLEM ASKS FOR THE RATIO OF MASS A/MASS B. THIS IS EQUIVALENT TO ACCEL.B/ACCEL.A DUE TO THE INVERSE RELATIONSHIP.

TRY THE QUESTION AGAIN.

WHAT IS THE RATIO: MASS A/MASS B?

?1/4

CORRECT!

YOU HAVE NOW COMPLETED THIS SIMULATED EXPERIMENT. PERHAPS YOU WILL BE ABLE TO PURSUE THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB.

AFTER YOU'VE SIGNED OFF THE TERMINAL FILL OUT SEVERAL EXTRA INCHES OF PAPER. ON IT LIST THE SOURCES OF EXPERIMENTAL ERROR AS YOU ENVISION THEM AND STATE THE MAJOR CONCLUSIONS YOU CAN DRAW FROM THE EXPERIMENT. INCLUDE THIS PAPER IN YOUR PHYSICS NOTEBOOK.

AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM LOOP 'FORCE & MOTION IV' AND SON 'FORCED'.

TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY.

DONE

FORCED

HI! IN THIS FINAL PROGRAM OF THE SERIES WE WILL DISCUSS WHAT WE'VE LEARNED ABOUT FORCE AND MOTION AND INTRODUCE A SYSTEM OF UNITS IN COMMON USE. HAVE YOU COMPLETED 'FORCEC' AND THEN STOP
HEL-LOO1,E,3

05-14-74 02:42 PM PORT #17

S

STOP

GET-FORCED

RUN

FORCED

HI! IN THIS FINAL PROGRAM OF THE SERIES WE WILL DISCUSS WHAT WE'VE LEARNED ABOUT FORCE AND MOTION AND INTRODUCE A SYSTEM OF UNITS IN COMMON USE. HAVE YOU COMPLETED 'FORCEC' AND THEN VIEWED FILM LOOP 'FORCE & MOTION IV'?
YES

IN THE FIRST EXPERIMENT WE OBSERVED THAT A CONSTANT FORCE CAUSES A BODY TO UNDERGO A CONSTANT ACCELERATION. IN THE 2ND EXPERIMENT WE OBSERVED THAT ACCELERATION WAS DIRECTLY PROPORTIONAL TO THE NET FORCE. IN THE 3RD EXPERIMENT WE OBSERVED WHAT KIND OF RELATIONSHIP BETWEEN ACCELERATION AND MASS?
INVERSE

CORRECT! WE MAY WRITE THIS LAST STATEMENT AS:

- 1) a IS DIRECTLY PROPORTIONAL TO $1/a$ OR
- 2) a IS DIRECTLY PROPORTIONAL TO $1/m$

FROM THE RESULTS OF EXPERIMENT 2 WE CAN WRITE:

- 3) a IS DIRECTLY PROPORTIONAL TO F

STATEMENTS (2) & (3) CAN BE COMBINED AND WRITTEN AS:
 a IS DIRECTLY PROPORTIONAL TO F/m

AN EQUIVALENT STATEMENT IS:

ma IS DIRECTLY PROPORTIONAL TO F
OR: F IS DIRECTLY PROPORTIONAL TO ma

IN EQUATION FORM:
 $F=ma$

I'VE JUST TYPED A LOT OF INFORMATION HERE. READ IT CAREFULLY AND TYPE 'GO' WHEN YOU WANT ME TO CONTINUE.

?GO

IN THE EQUATION K IS A CONSTANT OF PROPORTIONALITY AND ITS NUMERICAL VALUE DEPENDS UPON THE UNITS USED TO MEASURE FORCE, MASS, AND ACCELERATION. IT WOULD HAVE A SPECIFIC VALUE IF WE CONTINUED TO MEASURE FORCE IN 'BANDS' AND MASS IN 'BRICKS'. THE UNITS WE USED HAPPENED TO BE CONVENIENT FOR US, BUT THEY ARE NOT IN COMMON USE IN THE WORLD. THE EQUATION, OFTEN REFERRED TO AS NEWTON'S 2ND LAW, IS PERHAPS THE MOST FUNDAMENTAL EQUATION IN CLASSICAL MECHANICS, AND THE UNIT OF FORCE COMMONLY USED IS DEFINED SO THAT K IN THE EQUATION = 1.

IN SCIENTIFIC WORK A VERY COMMON UNIT OF MASS IN USE TODAY IS THE KILOGRAM (KG). THE BASIC UNIT OF FORCE WILL CAUSE A MASS OF 1 KILOGRAM TO ACCELERATE AT 1M/SEC/SEC . THIS UNIT OF FORCE IS CALLED THE NEWTON (N). IN OTHER WORDS A FORCE OF 1N WILL CAUSE A MASS OF 1KG TO ACCELERATE 1M/SEC/SEC . USING THESE UNITS THE EQUATION IS WRITTEN:

$$F=MA$$

$$1\text{N}=1\text{KG M/SEC/SEC}$$

TRY THE FOLLOWING PROBLEM USING THE MKS (METER, KILOGRAM, SECOND) SYSTEM OF UNITS. A 600KG SPACESHIP IS PROPELLED BY A ROCKET ENGINE. ITS ACCELERATION IS 2M/SEC/SEC . WHAT IS THE NET FORCE (IN NEWTONS) ACTING ON THE SPACESHIP?
?1200

CORRECT! NOW HERE'S A SLIGHT VARIATION OF THE SAME PROBLEM: AN 80KG ASTRONAUT IN EQUILIBRIUM OUTSIDE HIS SPACESHIP RECEIVES A 40N FORCE FROM A PROPULSION JET ATTACHED TO HIM. WHAT ACCEL. (IN M/SEC/SEC) DOES HE EXPERIENCE?
?.5

RIGHT! IT IS IMPORTANT TO POINT OUT AS I DID IN EXP. 2 THAT F REPRESENTS THE VECTOR SUM OF ALL FORCES ACTING ON THE OBJECT.

TRY THIS PROBLEM AGAIN WHICH INVOLVES NEGATIVE ACCELERATION: A 2000 KG CAR IS TRAVELLING AT A SPEED OF 30M/SEC WHEN THE BRAKES ARE APPLIED. THE CAR STOPS IN 15 SEC. IF WE ASSUME A CONSTANT ACCELERATION, WHAT WAS THE FORCE (IN N) APPLIED BY THE BRAKES?
?4000

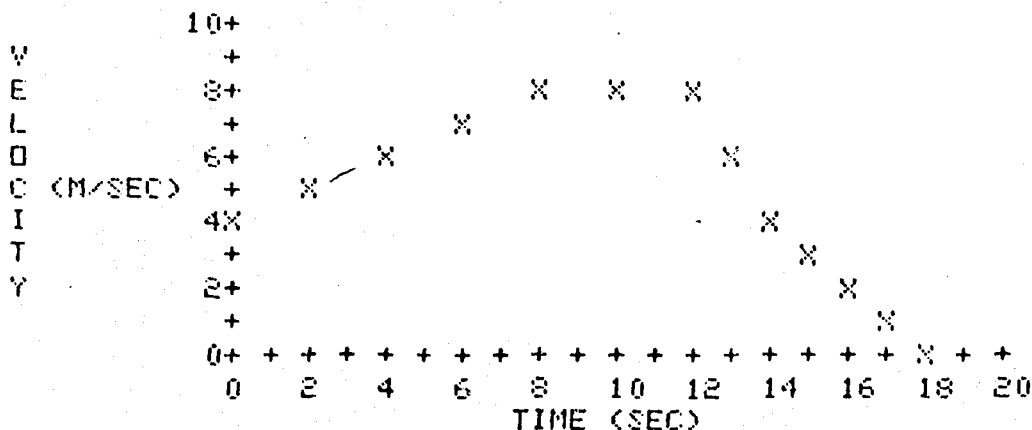
GOOD! THE NEGATIVE BRAKING FORCE PRODUCED A NEGATIVE ACCEL. IF THE VECTOR SUM OF THE FORCES ON A OBJECT = 0, THEN THE OBJECT WILL UNDERGO 0 ACCELERATION. IN OTHER WORDS ITS VELOCITY WILL NOT CHANGE. HERE'S A PROBLEM ON THE SUBJECT: TO PUSH MY STOVE ACROSS MY KITCHEN FLOOR AT A CONSTANT SPEED OF 1M/SEC , I MUST APPLY A FORCE OF 250N.

WHAT IS THE FRICTIONAL FORCE ACTING ON THE STOVE IN N?
?250

DUPE! NOW TRY THIS PROBLEM: A FORCE OF 12N GIVES MASS A AN ACCEL. OF 2M/SEC^2 AND MASS B AN ACCEL. OF 6M/SEC^2 . WHAT IS THE ACCEL. (IN M/SEC^2) WHEN THE TWO ARE FASTENED TOGETHER AND THE SAME FORCE IS APPLIED?
?1.5

GOOD!

THE LAST FEW QUESTIONS DEAL WITH THE GRAPH PRINTED BELOW WHICH SHOWS THE VELOCITY OF A 10KG OBJECT ALONG A STRAIGHT PATH.



IN THE NEXT 3 QUESTIONS TYPE IN THE LETTER OF THE BEST RESPONSE:

1. THE NET FORCE ACTING ON THE OBJECT WAS 0 AT: (A) 0 SEC; (B) 4SEC; (C) 10SEC; (D) 13SEC; (E) 16SEC; (F) NONE OF THE ABOVE
?C

CORRECT!

2. THE NET FORCE ACTING ON THE OBJECT WAS GREATEST AT:
(A) 0 SEC; (B) 4 SEC; (C) 10 SEC; (D) 13 SEC; (E) 16 SEC;
(F) NONE OF THE ABOVE.
?D

GOOD!

3. THE NET FORCE WAS CONSTANT BETWEEN: (A) 6-9SEC; (B) 9-13SEC;
(C) 13-15SEC; (D) 15-18SEC; (E) NONE OF THE ABOVE
?B

INCORRECT. THE FORCE IS CONSTANT WHERE THE ACCEL. IS CONSTANT. REMEMBER THAT THE ACCEL. AT ANY POINT IS THE SLOPE OF THE V VERSUS T GRAPH. FIND THE LISTED TIME INTERVAL IN WHICH VELOCITY CHANGES AT A CONSTANT RATE, AND TYPE IN THE CORRECT ANSWER.
?D

CORRECT!

4. WHAT WAS THE ACCEL. OF THE OBJECT (IN M/SEC/SEC) AT 6 SEC?
 ?5
 FINE!

5. DETERMINE THE NET FORCE (IN N) AT 6 SEC. (OBJECT HAS MASS OF 10KG)
 ?60

WRONG. $F=MA$. MULTIPLY THE MASS(10KG) BY THE ACCEL. CALCULATED IN THE
 LAST PROBLEM. CHECK YOUR CALCULATIONS AND TYPE IN THE CORRECT ANSWER.
 ?5

VERY NICE.

YOU'LL NOTICE ON THE GRAPH THAT THIS CONSTANT FORCE OF 5N WAS APPLIED
 FROM 0SEC THROUGH 8 SEC. NOW, THE FINAL PROBLEM:

6. DETERMINE THE FORCE (IN N) ACTING AT 13 SEC.
 ?20

OK! IT'S A GOOD IDEA TO WRITE THIS FORCE AS -20N SINCE
 THE FORCE IS OPPOSITE THE DIRECTION IN WHICH THE OBJECT IS
 MOVING.

THE IDEAS WE'VE BEEN DISCUSSING IN THESE FOUR PROGRAMS ARE
 FUNDAMENTAL IN CLASSICAL MECHANICS. OUR UNDERSTANDING OF THEM
 HAS BEEN GREATLY ENHANCED BY THE BRILLIANT INSIGHTS PROVIDED
 BY GALILEO, NEWTON, AND THEIR SUCCESSORS. THE STORY OF THE WORK
 OF THESE EARLY SCIENTISTS IS FASCINATING READING.
 THESE IDEAS PROVIDE A STARTING POINT FOR FURTHER STUDY IN
 MECHANICS. VERY SOON, FOR EXAMPLE, YOU WILL STUDY FALLING
 BODIES. WHEN A BODY FALLS THE FORCE CAUSING IT TO ACCELERATE
 IS ITS WEIGHT...

IT HAS BEEN VERY NICE WORKING WITH YOU IN THESE PAST FOUR
 EXPERIMENTS. PERHAPS WE'LL MEET AGAIN IF SOMEONE WILL WRITE
 MORE PROGRAMS...?

BEFORE WE PART, YOU'LL HAVE TO TYPE IN THE EQUATION REPRE-
 SENTING NEWTON'S 2ND LAW WHICH WE DEVELOPED IN THIS PROGRAM.
 BEGIN THE EQUATION: $F = \dots$ AND DO NOT INCLUDE A MULTIPLICATION SIGN.
 ? $F=MA$

AUF WIEDERSEHEN

TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY.

BYE

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

INSTRUCTIONAL OBJECTIVES

technical report 1

GENERAL OBJECTIVES

General instructional objectives of the Force and Motion unit are:

- A. to provide the student with a detailed understanding of Newton's Second Law;
- B. to help the student develop graphical skills and an ability to interpret graphed data;
- C. to help the student develop inquiry skills;
- D. (for Group I students only) to familiarize the student with the computer.

BEHAVIORAL OBJECTIVES

The instructional objectives may be stated in more specific behavioral form. Prior to beginning the Force and Motion unit the student should have studied certain prerequisite concepts and skills for which the unit does provide reinforcement and a limited amount of assistance in the event of conceptual difficulty. When the student has mastered the entry concepts and skills he will be able to:

1. determine the acceleration of an object given data describing its change in velocity;
2. describe the velocity and acceleration of an object when no net force is applied (Newton's First Law);

3. determine the slope and intercept values when given a linear graph;

4. write an equation to fit the data when given a linear graph.

At the completion of the Force and Motion unit the student should have mastered additional concepts and process skills such that he should be able to:

5. determine the acceleration given the force applied to an object;

6. determine the force acting on an object given its acceleration (in Newtons or in arbitrary force units);

7. determine the mass of an object given the force applied and the resulting acceleration;

8. determine the applied forces given data describing the velocity of an object at various times;

9. describe the effects of forces on an inertial mass;

10. describe the effects of a constant force on the motion of an object;

11. determine the frictional force from a graph of force versus acceleration for an object;

12. describe the effects of friction on the acceleration of an object when a force is applied;

13. determine where velocity, acceleration, and force are maximum, constant, and minimum respectively given a velocity versus time graph;

14. fit an equation to a first order inverse relationship;

15. plot the velocity of an object as a function of time given a ticker tape pulled by the object through a timer;

16. describe the effects of experimental error on the variables under investigation.

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

MESSAGES TO STUDENTS AND TEACHERS

technical report

FORCE & MOTION

Computer Simulation

Message to Students

These four computer programs which you are about to use simulate experiments in force and motion. They will help you understand some basic ideas in physics. If you have never used a computer terminal before, don't panic, for it is much less intelligent than you are. It can, however, do some things faster than you can - as you will see. You don't have to know any special computer language to use these programs; it will help though, if you know how to use the English language!!

Typed below are some special instructions which will enable you to use the physics programs which are available in the computer.

1. Turn on Power (Power Off)
2. Dial - ___ ___ and listen for high pitch tone
3. Place phone in coupler
4. At Keyboard type: HEL - ____, ____, then press RETURN Key. (If all is well the computer will type: READY)
5. Type: GET - \$FORCEA, then press RETURN Key
6. Type: RUN

From here on all other instructions will be typed out for you by the computer. Read the messages carefully. Whenever a question mark appears on the left-hand side of the paper and the teletypewriter stops printing, you must type in a response and then press the RETURN key. The computer is looking for short responses in answer to its questions like: DIRECT, or 27, or CONSTANT.

Here are three notes of procedure:

1. To represent the number one (1) you must use the key labeled with the numeral 1 which is located at the left of the top line on the keyboard.
2. To represent the quantity zero, you must use the key labeled 0 located at the right of numeral 9 on top line of keyboard.

3. When making your responses, do not type in any extra spaces. (The computer has not been programmed to recognize them in these simulations.)

If you make an error in typing which you wish to correct before you press the RETURN key, one method you may use to correct your answer is: Hit the ESC (ESCAPE) key which is located in the upper left corner of the keyboard and then retype the correct answer.

To terminate: Type BYE then press RETURN key. Then Push Power ON switch and light will go off.

Make appropriate entry in LUNET LOG (time is expressed in minutes on data sheet such as: "006 minutes of terminal time.")

The four Force and Motion programs are named: FORCEA; FORCEB; FORCEC; FORCED.

FORCE & MOTION

Computer Simulations

To: Physics Teachers

SUBJECT: Instructions regarding students whose programs have been terminated due to poor understanding of a concept.

A non threatening attitude should exist such that students whose programs have been terminated due to poor understanding of a concept readily come for consultation with their teachers. After discussing the concept thoroughly with the student, the teacher may recommend one of the following three options:

1. The student should rerun the entire program from the beginning in order to gain additional experience.
2. The student should proceed with the next program in the series if the teacher feels that the student understands the concept well and would not profit from rerunning the program.
3. The student should begin again, in the middle of the program which was terminated, and complete the remaining part of the program.

The following table indicates line numbers at which students can restart their programs. The instructions to be typed into the computer after signing on are, e.g.

GET-FORCEA
RUN-910

<u>Program</u>	<u>Starting Point</u>	<u>RUN</u>
FORCEA	Problem at the end of the program	910
FORCEB	Problems at the end of the program	1260
FORCEC	Problems at the end of the program	1270
FORCED	80 kg astronaut problem	460
	Braking car problem	580
	Kitchen stove problem	700
	2 masses fastened together	800
	Graph problems	880

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

EVALUATION INSTRUMENTS

technical report 1

Evaluation Instruments

The instruments used in data collection for this unit include a criterion-referenced pretest, a criterion-referenced posttest, and a student attitude survey. A description of the evaluation instrument follows:

Pretest. This examination is a forty item, multiple choice response, criterion-referenced test which measures cognitive skills. Test items were adapted from several sources. The largest number of items were adapted from a set of tests developed by Harvard Project Physics.³ Other items were written by the author, and some were constructed from problems in the PSSC text.⁴ In a study conducted by the author, the KR_{21} reliability estimate was .85. The test may be administered to assess the entry behaviors of the students participating in the unit.

Posttest. This final examination is an alternate form of the Pretest. Numerical values in the items and the names of objects described in the test have been changed from those in the Pretest; also the item sequence is changed. Items on the test measure the attainment of the behavioral objectives specified in the objectives section of this report. The KR_{20} reliability estimate is .78. The test measures the student's cognitive growth attained through the unit when his score is contrasted with that on the Pretest.

3 Harvard Project Physics. Tests, Unit I. New York: Holt, Rinehart, and Winston, Inc., 1968.

4 Physical Science Study Committee, op. cit., p. 332-334.

Student Attitude Survey. This survey was designed to assess the student's attitudes toward the method of presentation of the unit. The majority of items in the survey were adapted from items on an instrument developed to measure student attitudes toward Computer Assisted Instruction by Bobby R. Brown.⁵

5 Bobby R. Brown. "Student Attitude Toward Computer-Assisted Instruction." Computer-Assisted Instruction Center, Florida State University, Tallahassee, Florida.

FORCE & MOTION

TEST

DIRECTIONS: This is a 30 minute test. Do not open this test booklet until you are asked to do so.

When you do write on the answer sheet, be sure to use only an ordinary #2 pencil. No ink or ball point pens may be used.

Turn your answer sheet so that the blue striped area is on your right. In the upper left corner, write in the name of the school and your instructor on the appropriate lines. On the line labelled CITY write in the date.

In the upper right corner you will see a group of columns labelled "Print your name in the boxes provided...". Print your last name, your first name, and your middle initial in the boxes provided. If there are extra boxes, leave them blank.

In the lower right section of the answer sheet, print your GRADE, BIRTH DATE, and SEX in the columns provided.

Go down the column under each of the boxes in which you have entered a letter and blacken the space that contains the letter.

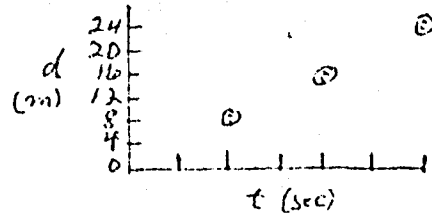
Make sure that all marks on the answer sheet are black and heavy and completely fill the answer spaces. Do not place any marks on the test booklet.

Answer all questions in the test by marking the letter on the answer sheet corresponding to the one best answer.

DO NOT OPEN THIS TEXT BOOKLET UNTIL YOU ARE ASKED TO DO SO.

1. An experiment yielded the data given in the table and graph below.

t (sec)	d (m)
0	0
2	8
4	16
6	24



If these data are expressed as an equation, $d=kt$, the value of k is

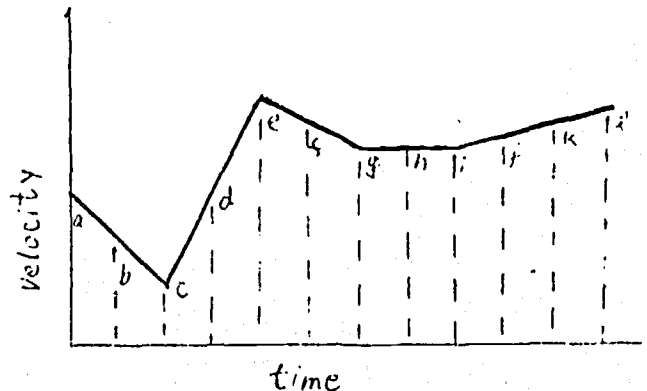
- A. 2 m/sec
 B. 2 sec/m
 C. 4 m/sec
 D. 4 sec/m
 E. 0.5 m/sec
2. Which of the following increases with time if a car moves with uniform velocity?
- A. direction
 B. displacement
 C. acceleration
 D. applied force
 E. average velocity

Questions 3-7 refer to the graph at the right.

3. The speed is greatest at the time corresponding to point
- A. a D. e
 B. c E. k
 C. d

4. The magnitude of the acceleration is greatest in the time interval

- A. a to c D. g to i
 B. c to e E. i to k
 C. e to g



5. The applied force was 0 in the time interval

- A. a to c D. g to i
 B. c to e E. i to k
 C. e to g

6. The magnitude of the applied force is greatest in the time interval

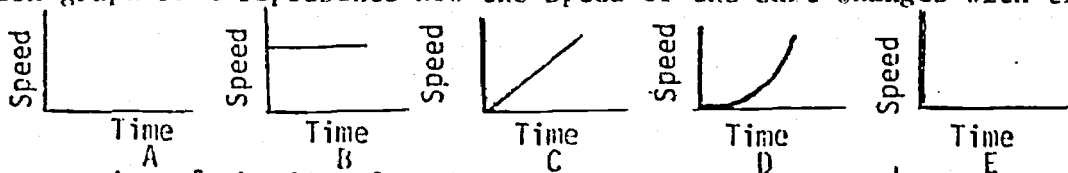
- A. a to c D. g to i
 B. c to e E. i to k
 C. e to g

7. The applied force reaches its maximum negative value in the time interval

- A. a to c D. g to i
 B. c to e E. i to k
 C. e to g

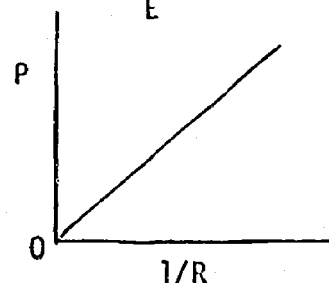
8. A car has a maximum acceleration of 4 m/sec^2 . If it tows a second car having the same mass and design, the maximum acceleration will be
- 0 m/sec^2
 - 2 m/sec^2
 - 4 m/sec^2
 - 6 m/sec^2
 - 8 m/sec^2

9. A cart, initially at rest, is pulled with a constant, unbalanced force. Which graph best represents how the speed of the cart changes with time?

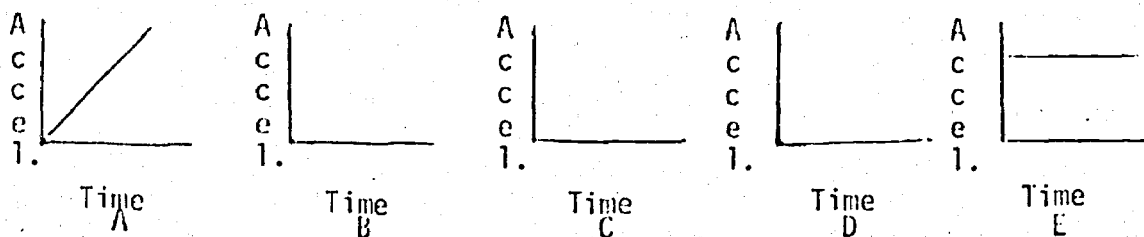


10. The equation of the line for the graph at the right is

$$\begin{array}{ll} \text{A. } P = \frac{K}{R} & \text{D. } P = K\sqrt{R} \\ \text{B. } P = KR & \text{E. } P = KR^2 \\ \text{C. } P = \frac{K}{R^2} & \end{array}$$



11. A man pushes a puck on a frictionless horizontal surface with a force of 20 newtons. The resulting acceleration is 8.0 m/sec^2 . What is the mass of the puck?
- 0.4 kg
 - 2.5 kg
 - 4.0 kg
 - 10 kg
 - 40 kg
12. A car is slowed by a braking force that it comes to rest in 20 sec. If the car travels at the same speed and the braking force is doubled,
- the acceleration will be for times the previous value.
 - the change in velocity will be doubled.
 - the car will come to rest in 10 seconds.
 - the car will come to rest in 40 seconds.
 - the car will come to rest in half the distance.
13. To push my desk across the floor at a constant speed of 2 m/sec , I must apply a force of 200 newtons. The force of friction acting on the desk is
- 0 newtons
 - 100 newtons
 - 200 newtons
 - 400 newtons
 - Impossible to determine from the information given
14. Which of the following graphs shows the effects of a constant force?

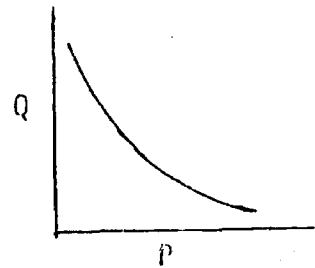


15. An astronaut in space gives a sudden push to a box that sends it away from him. Consider the following statements (assume friction is negligible).
1. The force exerted on the box by the astronaut is equal in magnitude to the force exerted on the astronaut by the box.
 2. During the push the acceleration of the astronaut is equal in magnitude to the acceleration of the box.
 3. The astronaut will accelerate for the same length of time as the box.

Which of the statements is true if the astronaut and the box have the same mass?

- A. 1 only
 B. 2 only
 C. 3 only
 D. 2 and 3 only
 E. 1, 2, and 3

16. For the graph shown on the right, indicate the action you would take in order to work toward finding the relationship?

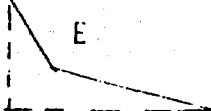
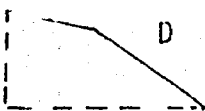
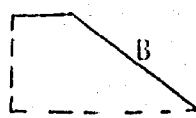


- A. Square the P variable and graph Q vs. P^2
 B. Take square root of P variable and graph Q vs. \sqrt{P}
 C. No additional graph is needed.
 D. Take inverse of P variable and graph Q vs. $1/P$
 E. Take square root of Q variable and graph \sqrt{Q} vs. P

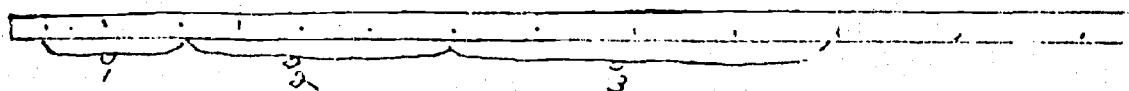
17. Measurements made on a ball rolling down a hill of unknown shape provided the following data:

Time	Instantaneous Speed
0 sec	0 m/sec
1	6
2	12
3	18
4	20
5	22
6	24

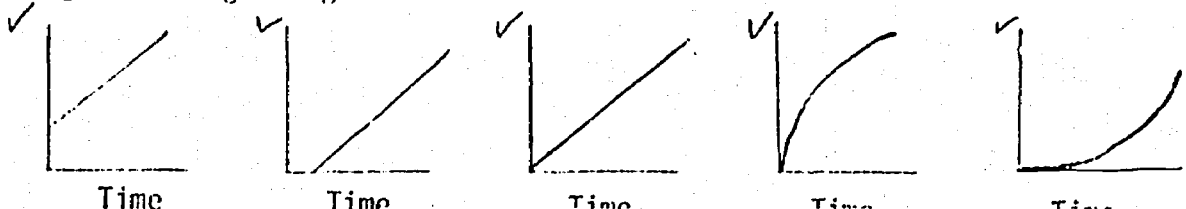
Which of the following diagrams represents the shape of the hill?



- 18.

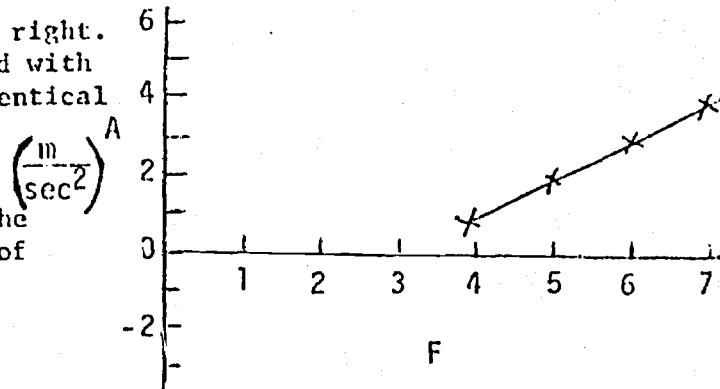


The graph most nearly describing the motion on the ticker tape above from the beginning of interval 2 is:



19. The acceleration of an object may be doubled by
- doubling its mass
 - doubling its velocity
 - doubling its weight
 - doubling the net force acting upon it
 - none of the above
20. A railroad passenger car is at rest in a railway station. A boy sitting in the car flips a dime into the air; the dime hits the floor. Later, when the car is moving at a high constant speed, he flips the dime again in exactly the same way. Where does the dime hit the floor?
- At the same spot on the floor as before
 - Ahead of where it hit before
 - Behind where it hit before
 - Impossible to determine from the information given

Questions 21 - 24 refer to the graph at the right. In each of several trials, a cart was pulled with a different number of equally-stretched, identical rubber bands. A constant acceleration was observed in each trial.

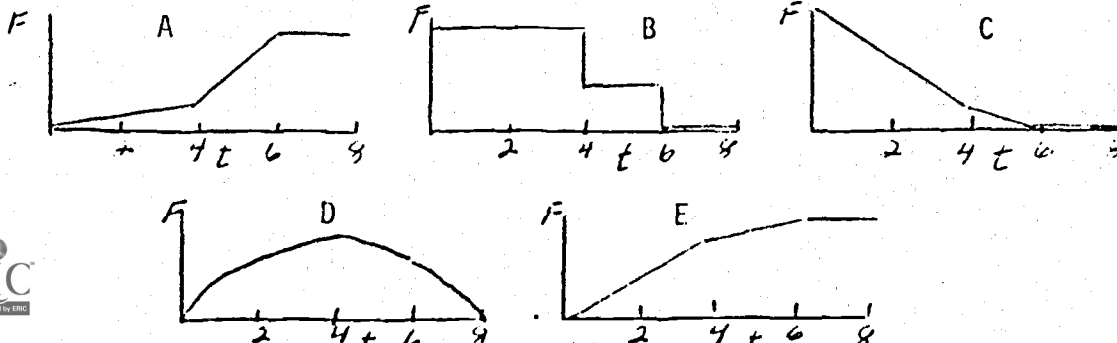


21. From the graph and your knowledge of the system, determine the number of bands of frictional force in the system.
- 0
 - 1
 - 2
 - 3
 - Impossible to determine from the information given.
22. From your knowledge of the system and from the graph, predict the acceleration of the cart when a force of two bands is applied.
- 2 m/sec/sec
 - 2 m/sec/sec
 - 1 m/sec/sec
 - 1 m/sec/sec
 - 0 m/sec/sec
23. If we change the surface on which the cart is pulled which of the following characteristics of the graph will probably change?
- Slope and F-intercept
 - F-intercept only
 - Slope only
 - Neither the slope nor the F-intercept will change
 - None of the above
24. An extrapolation of the graph produces an intercept on the force axis which is not 0. What does this indicate?
- The mass of the cart was neglected
 - There was a deviation from Newton's Laws
 - There was another force acting in the direction of motion
 - There was another force acting opposite the direction of motion
 - None of the above

25. A 1000 kg car is travelling at 40 m/sec when the brakes are applied. If the car stops in 10 sec, the average force applied to stop the car is
- A. 1000 newtons
B. 25 newtons
C. 250 newtons
D. 400,000 newtons
E. none of the above
26. All except one of the following require the application of a net force. Which one is the exception?
- A. to maintain an object in uniform circular motion.
B. to change an object from a state of rest to a state of motion
C. to change an object's speed without changing its direction of motion
D. to change an object's direction of motion without changing its speed
E. to maintain an object in motion at a constant velocity
27. A book is sitting at rest on a table. Which of the following statements best describes this situation?
- A. There are no forces acting on the book.
B. The book is at rest in any coordinate system.
C. The book exerts no force on the table.
D. There are many forces acting on the book, but they balance each other.
E. None of the above.
28. When the force applied to an object is constant, the object's acceleration and mass are
- A. directly proportional
B. equal
C. unrelated
D. 0
E. inversely proportional
29. When the net force acting on a cart equals 0, the cart
- A. ~~must~~ be at rest
B. may be in motion
C. may be speeding up
D. may be slowing down
E. none of the above
30. A plane having a mass of 10,000 kg. is launched from a catapult in 2.0 sec by a force of 400,000 newtons. Its average acceleration during launch was
- A. 40 cm/sec²
B. 1/40 m/sec²
C. 400 m/sec²
D. 1/400 m/sec²
E. 40 m/sec²

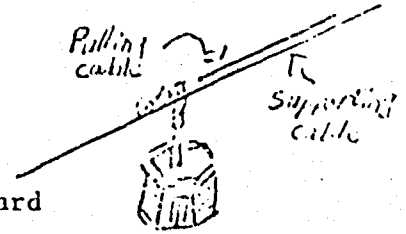
31. Given the velocity vs. time data at the right, select the force vs. time graph below that best illustrates that motion.

v	t
4	1
8	2
12	3
16	4
18	5
20	6
20	7
20	8



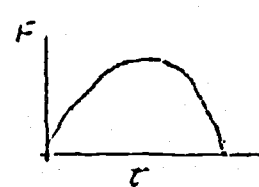
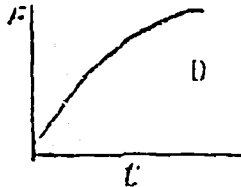
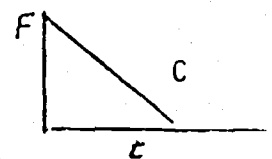
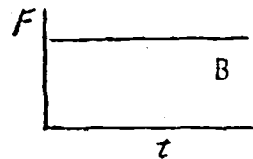
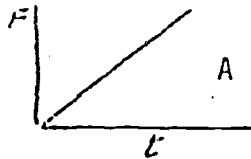
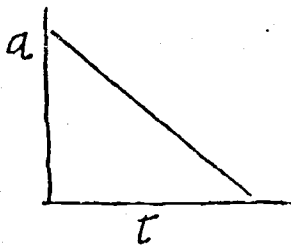
32. The diagram at the right shows a cable car supported by an overhead cable and pulled uphill by a second cable. Which of the following forces is 0 when the cable car moves with constant velocity?

- A. force of gravity on the car and carriage
- B. force exerted by supporting cables
- C. net unbalanced force on the car and carriage
- D. frictional force on the wheels of the carriage
- E. force exerted by the cable that pulls the car upward

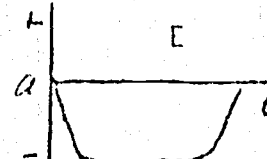
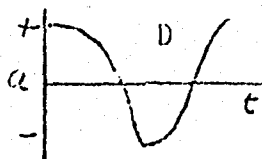
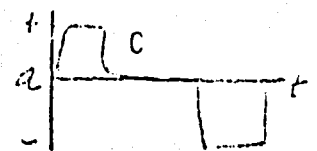
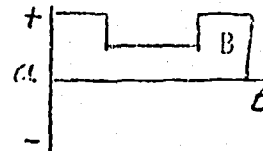
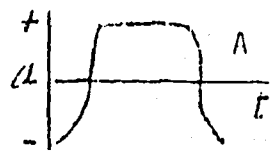
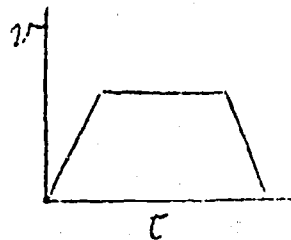


Given the graph at the left in each of the next three questions, pick the one at the right which most nearly describes the same phenomena. Examine the variables on the graphs carefully.

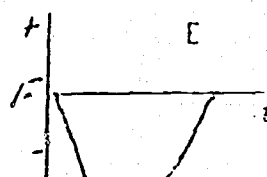
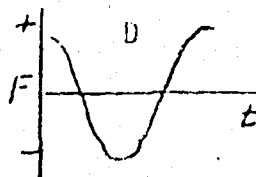
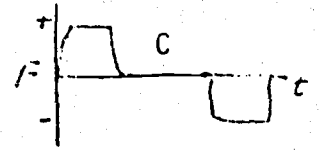
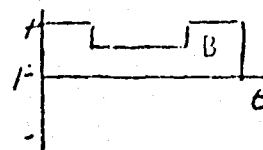
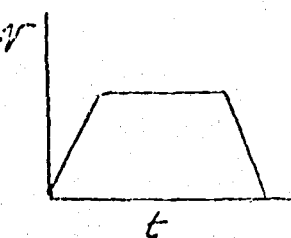
33.



34.

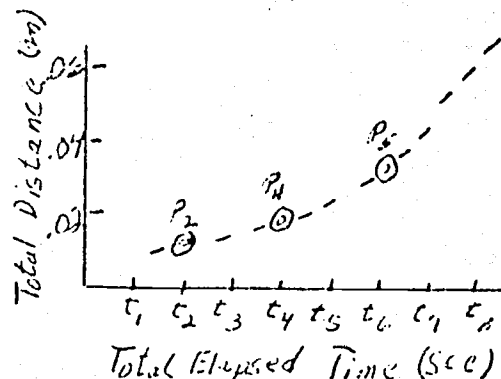


35.



The graph at the right shows the relationship between the time and the total distance traversed by a glider moving on a nearly frictionless air track. Points P_2 , P_4 , and P_6 represent the experimental measurements.

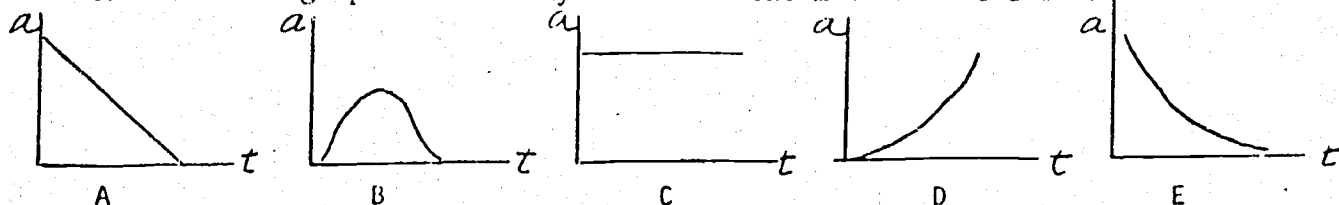
The dotted curve is a smooth curve drawn through these points. Questions 36 and 37 refer to this graph.



The slope of the curve at t_6 represents the

36. A. total distance traversed
B. rate of change of speed
C. instantaneous speed
D. acceleration
E. average speed
37. If the values of the total distance traversed at times t_5 , t_6 , and t_8 are arranged in order of uncertainty with the most uncertain value of distance first, the order is:
- A. t_5 t_6 t_8
B. t_8 t_5 t_6
C. t_5 t_8 t_6
D. t_6 t_5 t_8
E. t_6 t_8 t_5
38. A player kicks a .5 kg ball so that it acquires a speed of 20 m/sec in .4 sec. What was the average force applied to the ball during the kick?
- A. 4 newtons
B. 2.5 newtons
C. 25 newtons
D. 100 newtons
E. 10 newtons

39. A low-friction cart is filled with sand and a constant force is applied. As the cart moves, the sand falls out through a hole in the bottom of the cart. Which graph most nearly describes the motion of the cart?



40. Car A has a mass of 400 kg; car B has a mass of 1200 kg. If both cars are given the same acceleration, what is the ratio of the force applied to car A over the force applied to car B?
- A. 3
B. 1
C. .33
D. .67
E. 0

FORCE & MOTION

TEST

DIRECTIONS: This is a 30 minute test. Please do not open the test booklet until you are asked to do so.

When you do write on the answer sheet, be sure to use only an ordinary #2 pencil. No ink or ball point pens may be used.

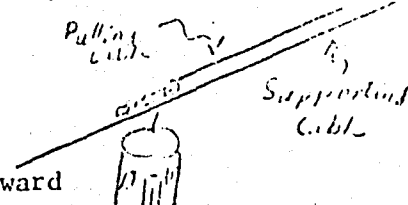
Turn your answer sheet so that the blue striped area is on your right. In the upper right corner you will see a group of columns labelled "Print your name in the boxes provided ...". Print your last name, your first name, and your middle initial in the boxes provided. If there are extra boxes, leave them blank.

Go down the column under each of the boxes in which you have entered a letter and blacken the space that contains the letter. Do this for your last name, your first name, and your middle initial.

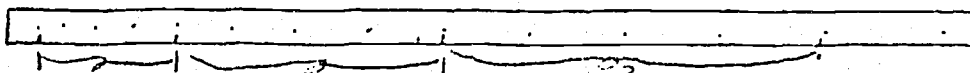
Make sure that all marks on the answer sheet are black and heavy and completely fill the answer spaces. Do not place any marks on the test booklet.

Answer all questions in the test by marking the letter on the answer sheet corresponding to the one best answer.

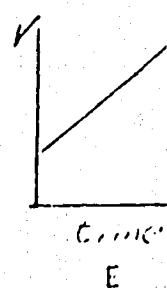
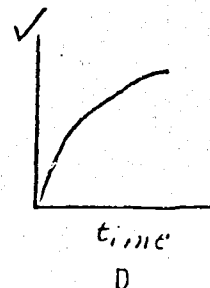
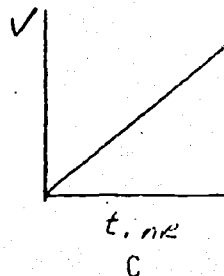
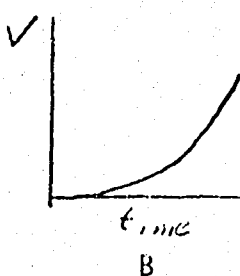
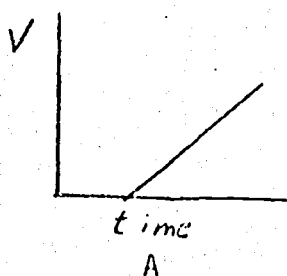
PLEASE DO NOT OPEN THIS TEST BOOKLET UNTIL YOU ARE ASKED TO DO SO.

- When the net force acting on a car equals 0, the car
 - must be at rest
 - may be in motion
 - may be speeding up
 - may be slowing down
 - none of the above
- This test paper is sitting at rest on your desk. Which of the following statements best describes this situation?
 - There are no forces acting on your paper.
 - Your paper is at rest in any coordinate system.
 - Your paper exerts no force on the desk.
 - There are many forces acting on your paper, but they balance each other.
 - None of the above.
- All except one of the following require the application of a net force. Which one is the exception?
 - to change an object from a state of rest to a state of motion
 - to maintain an object in motion at a constant velocity
 - to change an object's speed without changing its direction of motion
 - to maintain an object in uniform circular motion.
 - to change an object's direction of motion without changing its speed
- The diagram at the right shows a cable car supported by an overhead cable and pulled uphill by a second cable. Which of the following forces is 0 when the cable car moves with constant velocity?
 
 - net unbalanced force on the car and carriage
 - frictional force on the wheels of the carriage
 - force of gravity on the car and carriage
 - force exerted by supporting cables
 - force exerted by the cable that pulls the car upward
- A subway car is at rest in a subway station. A boy sitting in the car flips a dime into the air; the dime hits the floor. Later, when the car is moving over a straight, level section of track at a high constant speed, he flips the dime again in exactly the same way. Where does the dime hit the floor?
 - at the same spot on the floor as before
 - ahead of where it hit before
 - behind where it hit before
 - impossible to determine from the information given
 - none of the above

6.



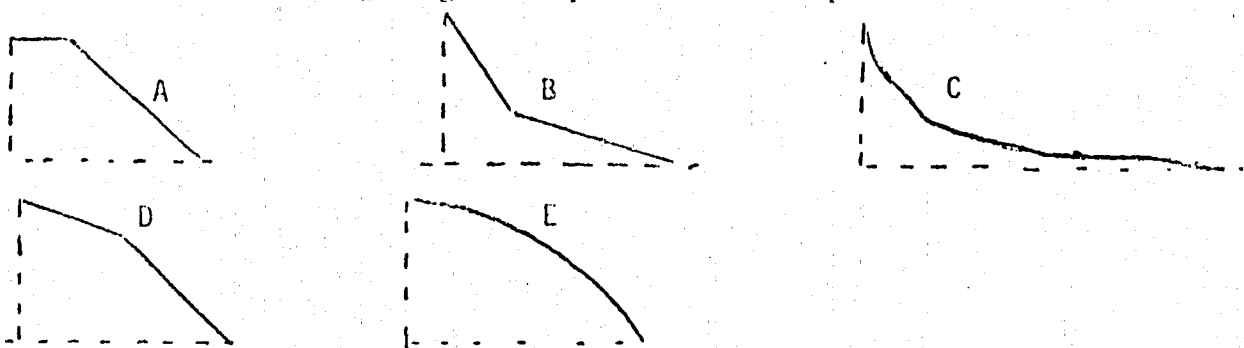
The graph most nearly describing the motion shown on the ticker tape above from the beginning of interval 2 is:



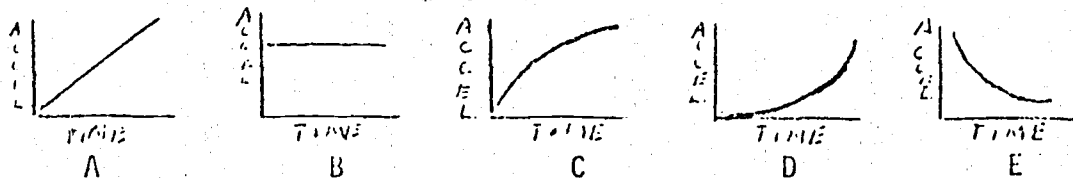
7. When the force applied to an object is constant, the object's acceleration and mass are
- directly proportional
 - equal
 - inversely proportional
 - unrelated
 - 0
8. The acceleration of an object may be tripled by
- tripling its mass
 - tripling its velocity
 - tripling its weight
 - tripling the net force acting upon it
 - none of the above
9. Which of the following increases with time if an object moves with uniform velocity?
- applied force
 - average velocity
 - acceleration
 - direction
 - displacement
10. Measurements made on a ball rolling down a hill of unknown shape provided the following data:

Time	Instantaneous Speed
0 sec	0 m/sec
1	6
2	12
3	18
4	20
5	22
6	24

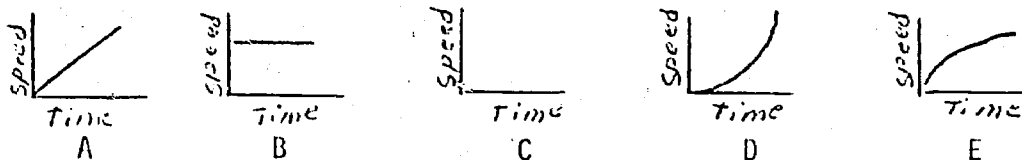
Which of the following diagrams represents the shape of the hill?



11. Which of the following graphs shows the effects of a constant force?

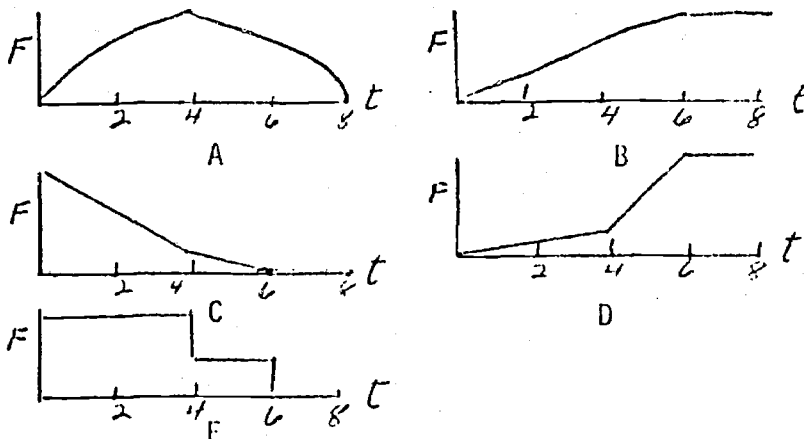


12. A car initially at rest, is pulled with a constant, unbalanced force. Which graph best represents how the speed of the cart changes with time?



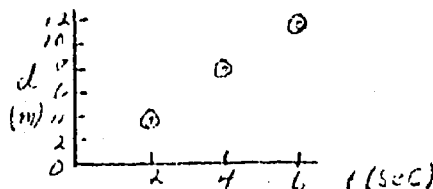
13. Given the velocity vs. time data at the right, select the force vs. time graph below that best illustrates that motion.

v	t
4	1
8	2
12	3
16	4
18	5
20	6
20	7
20	8



14. An experiment yielded the data given in the table and graph below.

t (sec)	d (m)
0	0
2	4
4	8
6	12

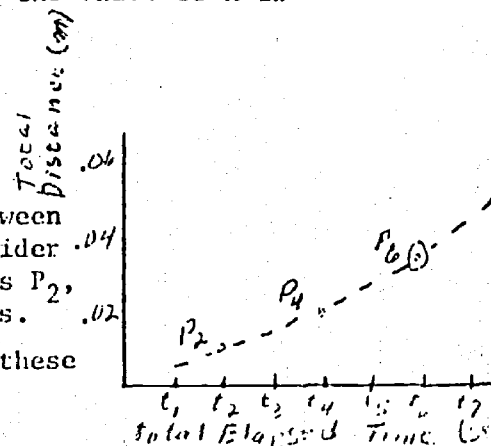


If these data are expressed as an equation, $d=kt$, the value of k is

- A. 1 m/sec
B. 1 sec/m
C. 2 m/sec
D. 2 sec/m
E. 0.5 m/sec

The graph at the right shows the relationship between the time and the total distance traversed by a glider moving on a nearly frictionless air track. Points P_2 , P_4 , and P_6 represent the experimental measurements.

The dotted curve is a smooth curve drawn through these points. Questions 15 and 16 refer to this graph.



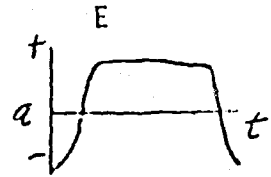
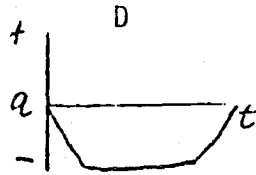
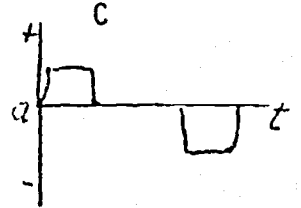
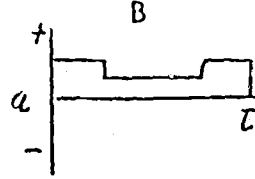
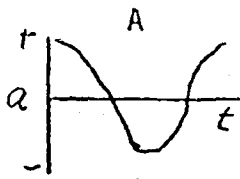
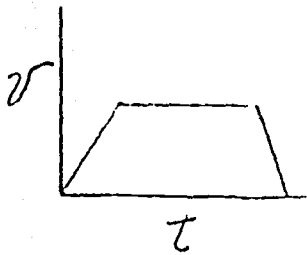
15. If the values of the total distance traversed at times t_5 , t_6 , and t_8 are arranged in order of uncertainty with the most uncertain value of distance first, the order is

- A. t_5 t_6 t_8
B. t_6 t_8 t_5
C. t_5 t_8 t_6
D. t_6 t_5 t_8
E. t_5 t_8 t_6

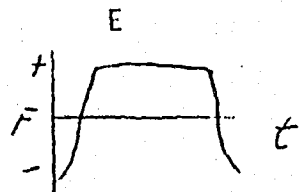
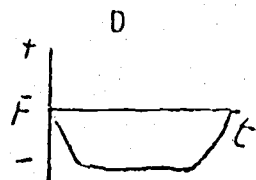
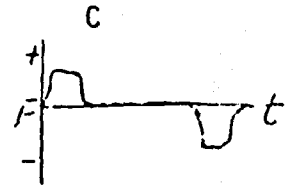
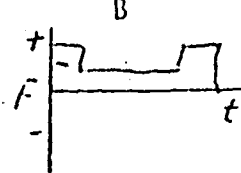
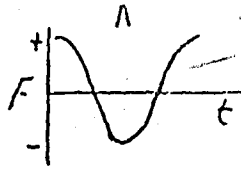
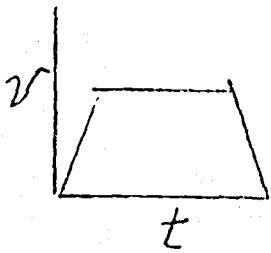
16. The slope of the curve at t_4 represents the
- total distance traversed
 - instantaneous speed
 - acceleration
 - rate of change of speed
 - average speed

Given the graph at the left in each of the next three questions, pick the one at the right which most nearly describes the same phenomena. Examine the variables on the graphs carefully.

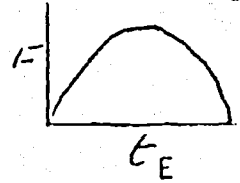
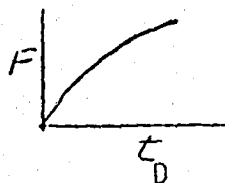
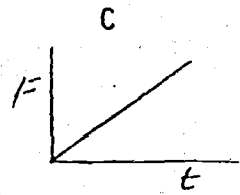
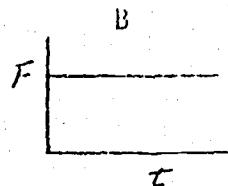
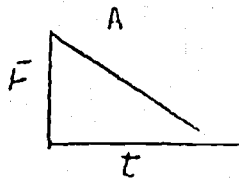
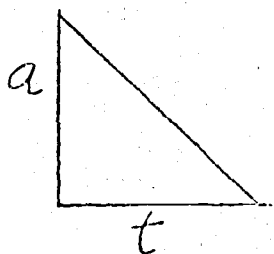
17.



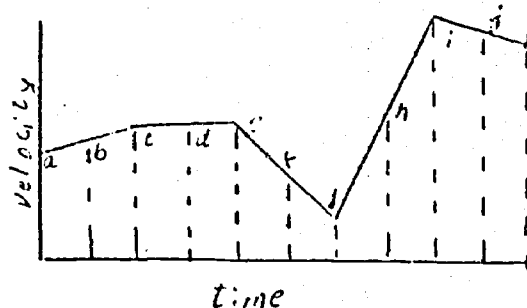
18.



19.

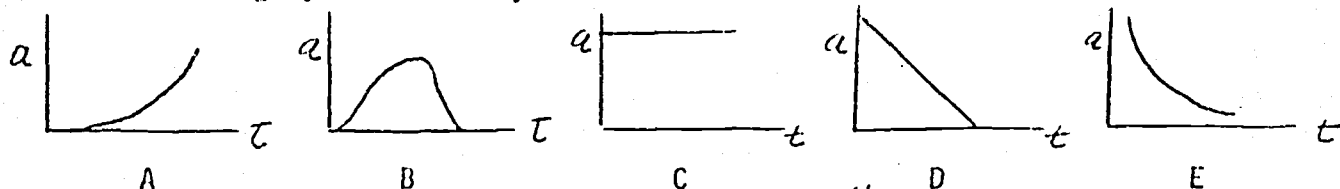


Questions 20 - 24, refer to the graph at the right.

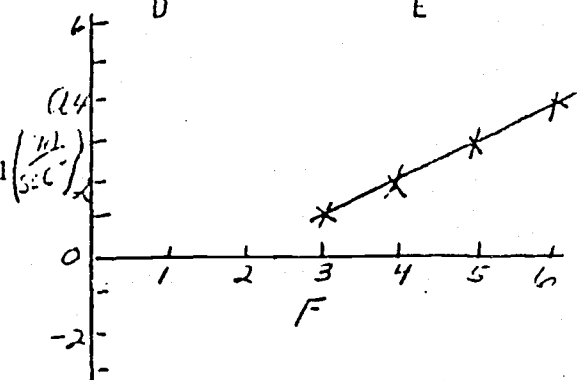


20. The magnitude of the acceleration is greatest in the time interval
 A. a to c D. g to i
 B. c to e E. i to k
 C. e to g
21. The speed is greatest at the time corresponding to point
 A. c D. i
 B. g E. k
 C. h
22. The magnitude of the supplied force is greatest in the time interval
 A. a to c D. g to i
 B. c to e E. i to k
 C. e to g
23. The applied force was 0 in the time interval
 A. a to c D. g to i
 B. c to e E. i to k
 C. e to g
24. The applied force reached its maximum negative value in the time interval
 A. a to c D. g to i
 B. c to e E. i to k
 C. e to g
25. To push my desk across the floor at a constant speed of 2 m/sec; I must apply a force of 150 newtons. The force of friction acting on the desk is
 A. 0 newtons D. 300 newtons
 B. 75 newtons D. Impossible to determine from the information given
 C. 150 newtons
26. An ice skater gives a sudden push to a sled that sends it sliding away from him. Consider the following statements (assume friction is negligible).
1. The force exerted on the sled by the skater is equal in magnitude to the force exerted on the skater by the sled.
 2. During the push the acceleration of the skater is equal in magnitude to the acceleration of the sled.
 3. The skater will accelerate for the same length of time as the sled.
- Which of the statements is true if the skater and the sled have the same mass?
- A. 1 only
 B. 2 only
 C. 3 only
 D. 2 and 3 only
 E. 1, 2, and 3

27. A car is slowed by a braking force so that it comes to rest in 10 sec. If the car travels at the same speed and the braking force is doubled,
- The acceleration will be four times the previous value.
 - The change in velocity will be doubled.
 - The car will come to rest in 5 seconds.
 - The car will come to rest in 20 seconds.
 - The car will come to rest in half the distance.
28. A low-friction cart is filled with sand and a constant force is applied. As the cart moves, the sand falls out through a hole in the bottom of the cart. Which graph most nearly describes the motion of the cart?



Questions 29 - 32 refer to the graph at the right. In each of several trials, a cart was pulled with a different number of equally-stretched, identical rubber bands. A constant acceleration was observed in each trial.



29. An extrapolation of the graph produces an intercept on the force axis which was not 0. What does this indicate?
- The mass of the cart was neglected.
 - There was a deviation from Newton's laws.
 - There was another force acting in the direction of motion.
 - There was another force acting opposite the direction of motion.
 - None of the above.
30. From the graph and your knowledge of the system, predict the acceleration of the cart when a force of one band is applied.
- 2 m/sec/sec
 - 2 m/sec/sec
 - 1 m/sec/sec
 - 1 m/sec/sec
 - 0 m/sec/sec
31. If we change the surface on which the cart is pulled which of the following characteristics of the graph will probably change?
- slope and F-intercept
 - F-intercept only
 - slope
 - Neither the slope nor the F-intercept will change
 - none of the above
32. From the graph and your knowledge of the system, determine the number of bands of frictional force in the system.
- 0
 - 1
 - 2
 - 3
 - impossible to determine from the information given

33. The equation of the line for the graph at the right is

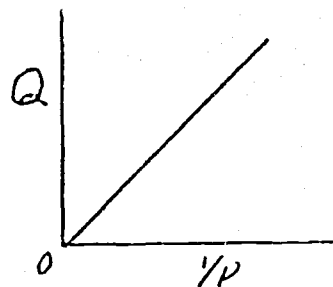
A. $Q = \frac{K}{P}$

D. $Q = K\sqrt{P}$

B. $Q = KP$

E. $Q = KP^2$

C. $Q = \frac{K}{P^2}$



34. For the graph shown on the right, indicate the action you would take in order to work toward finding the relationship.

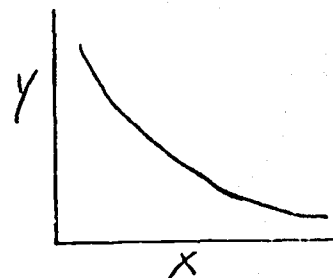
A. take inverse of x variable and graph Y vs. $1/X$

B. take square root of x variable and graph Y vs. \sqrt{X}

C. no additional graph needed

D. square the x variable and graph Y vs. X^2

E. take square root of y variable and graph \sqrt{Y} vs. X



35. A 2000 kg car is traveling at 50 m/sec when the brakes are applied. If the car stops in 10 sec. the average force applied to stop the car is

A. 8000 newtons

D. 800,000 newtons

B. 300 newtons

E. none of the above

C. 5 newtons

36. A man pushes a puck on a frictionless horizontal surface with a force of 10 newtons. The resulting acceleration is 4.0 m/sec^2 . What is the mass of the puck?

A. 0.4 kg

B. 2.5 kg

C. 4.0 kg

D. 10 kg

E. 40 kg

37. Car A has a mass of 500 kg; car B has a mass of 1500 kg. If both cars are given the same acceleration what is the ratio of the force applied to car A over the force applied to car B?

A. 3

D. .67

B. 1

E. 0

C. .33

38. A plane having a mass of 10,000 kg is launched from a catapult in 2.0 sec by a force of 300,000 newtons. Its average acceleration during launch was

A. 30 cm/sec^2

B. $1/30 \text{ m/sec}^2$

C. 300 m/sec^2

D. $1/300 \text{ m/sec}^2$

E. 30 m/sec^2

39. A car has a maximum acceleration of 5 m/sec^2 . If it tows a second car having the same mass and design, the maximum acceleration will be
- A. 0 m/sec^2
 - B. 2.5 m/sec^2
 - C. 5 m/sec^2
 - D. 7.5 m/sec^2
 - E. 10 m/sec^2
40. A player kicks a $.5 \text{ kg}$ ball so that it acquires a speed of 10 m/sec in $.2 \text{ sec}$. What was the average force applied to the ball during the kick?
- A. 4 newtons
 - B. 2.5 newtons
 - C. 25 newtons
 - D. 100 newtons
 - E. 10 newtons

FORCE & MOTION

Attitude Survey

DIRECTIONS: This is not a test of information; therefore, there is no one "right" answer to a question. We are interested in your opinion on each of the questions in this survey. Your opinions will be held strictly confidential. Do not hesitate to state exactly how you feel about each item. We are seeking information for an evaluation of the Force and Motion unit; please be "frank", and thank you for your help.

Please respond to each statement in the survey by marking your answer sheet according to the following code:

1. Strongly disagree
2. Disagree
3. Uncertain
4. Agree
5. Strongly agree

When you write on the answer sheet, be sure to use only an ordinary #2 pencil. No ink or ball point pens may be used.

Turn the answer sheet so that the blue striped area is on your right. In the upper left corner, write in the name of the school. On the line labelled CITY write in the date.

In the upper right corner you will see a group of columns labelled "Print your name in the boxes provided...". Print your last name, your first name, and your middle initial in the boxes provided. If there are extra boxes leave them blank. Go down the columns under each of the boxes in which you have entered a letter and blacken the space that contains the letter.

- RESPONSES:
1. STRONGLY DISAGREE
 2. DISAGREE
 3. UNCERTAIN
 4. AGREE
 5. STRONGLY AGREE

1. I felt I could work at my own pace in the Force & Motion unit.
2. The unit made learning too mechanical.
3. I found it difficult to concentrate on the unit because of the method of presentation.
4. The method of presentation of the unit made me feel tense.
5. While working in the unit, I felt isolated.
6. Responses to my answers were helpful and appropriate.
7. The Force & Motion unit was an efficient use of a student's time.
8. I could have learned more if I hadn't felt pushed.
9. Even interesting material will be boring, if it is presented as the Force & Motion unit was.
10. I am not in favor of this kind of instruction because it depersonalizes education.
11. After studying the Force & Motion unit, I was interested in finding out more about the subject matter.
12. The method of instruction was too inflexible.
13. While working in the unit I felt as if someone were engaged in conversation with me.
14. The Force & Motion unit made it possible for me to learn quickly.
15. I was not concerned when I missed a question because no one was watching me.
16. While working in the unit I felt as if I had a private tutor.
17. The Force & Motion unit made allowances for students with different levels of understanding.
18. I enjoyed the method of instruction used in the unit.
19. The Force & Motion method of instruction denied me the opportunity for self expression.
20. I prefer lectures and demonstrations to the method of instruction used in the unit.

21. The Force & Motion unit helped me in understanding the role of computers.
22. The flexibility of scheduling the unit caused me to be too casual about getting on the computer system, and I let things go for too long before I tried to run the programs.
23. During the unit I was more involved in running the computer than in understanding the material.
24. While using the Force & Motion unit, I encountered serious mechanical malfunctions in the computer system.

- RESPONSES:
1. STRONGLY DISAGREE
 2. DISAGREE
 3. UNCERTAIN
 4. AGREE
 5. STRONGLY AGREE

FORCE & MOTION

TEACHER REPORT

Name: _____ School: _____ Group: _____

Beginning date of unit (Pretest): _____ Ending date of unit (1st Posttest): _____

of class periods in unit: _____ Length of class period: _____

Approximate homework time per class period/student: _____

Date of 2nd Posttest: _____

Texts used by physics classes in the study: _____

What portion of a typical week would you normally devote to student experimentation?
(Ex. 40 min/week) _____

To what extent did the experimental unit take the place of your usual coverage of the material?

How would you rate your teaching facility (equipment, supplies, room size)?

Ex. _____ Good _____ Fair _____ Poor _____

How many years have you taught physics?

How many semester hours of course work have you had in the Physical Sciences?

0-10 _____ 10-20 _____ 20-30 _____ 30 or more _____

Did the work with the experimental unit make excessive demands upon your time?

Yes _____ No _____ Comments: _____

What other area of science teaching do you think would benefit most from the development of a computer supplemented unit similar to Force & Motion?

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

EVALUATION OF CLASSROOM USE

technical report 1

Students learned the concepts using the two simulation modes described in this Report, and they participated in one of the following three instructional groups:

Group I (Experimental). These students interacted only with the film loops developed in the study and with computer interactive dialogs in which the computer played the role of the student's lab partner. The dialogs simulated physical experiments in force and motion, graphed the unique data collected by individual students, and provided feedback to each student relative to his generalizations.

Group II (Experimental). These students did not have access to computer terminals and interacted with the film loops and with simulated data and problem sheets and their teachers. The simulated data and problem sheets were prepared from the computer lessons after the computer lessons had undergone initial revision.

Group III (Control). These students studied the same concepts as did students in the experimental groups interacting with their teachers and with real laboratory materials as a normal part of their physics course. (The particular units were built largely around laboratory exercises III-1 and III-2 and supporting text materials of the Physical Science Study Committee.)

METHOD

Subjects

Subjects in the study were physics students in five public high schools in Massachusetts and Connecticut. These students were in classes which met the following criteria:

1. The Physics teacher was regarded as highly competent by colleagues in science education;
2. The teacher was interested in having his classes participate in the study and was able to coordinate necessary arrangements;
3. Group I classes were in schools having access to the computer system which was to be used in the study;
4. Group III classes used PSSC laboratory materials with teachers who had used the particular materials in previous years and who regarded the particular PSSC laboratory exercises as very important and effective learning modules;
5. The student groups had similar academic and socio-economic environments.

Procedure

Students participating in the study were selected from physics classes which were as similar as possible. All students within a particular class were members of the same group and were not aware of the activities of any of the other experimental or control groups.

Teachers in all groups brought their students through specified preliminary activities and then administered Pretests just prior to having their students begin the experimental unit. Immediately upon concluding unit activities, Posttests were administered to all students. The experimental unit was conducted in all classes within the first three months of the school year (September - December 1970), and activities during this period were carefully controlled and recorded. Following the first Posttest (Posttest #1) the classes participating in the study proceeded independently through various materials which were not experimentally controlled or recorded by the researcher.

In June of 1971, a second Posttest (Posttest #2) was administered to all students participating in the study. This second Posttest was identical to the one which had been taken by the students at the conclusion of the experimental unit. It was used to assess retention in the various experimental and control groups when scores were contrasted with those on the first Posttest. The Student Attitude Survey was also administered at this time to students in Groups I and II to assess their attitudes toward the experimental unit in the context of the entire physics course.

RESULTS

1. Which of the three instructional treatments produced best student performance?

Before the instructional groups were compared with each other, a t test was used to study the change in conceptual understanding from Pretest to Posttest #1 for each instructional group. Test data for each of the three instructional groups displayed in Table I indicated that student knowledge of physical concepts as measured by the tests was significantly higher at the conclusion of the unit than it was at the beginning.

To obtain a gross comparison of the effects of the instructional treatments, an analysis of variance (ANOVA) was conducted on the Pretest-Posttest #1 difference scores for the three groups. The analysis showed (Table II-A) that there were significant differences between the instructional groups; students in Group I had made the greatest gains followed by students in Groups II and III in that order.

TABLE I

PRETEST - POSTTEST #1 COMPARISON
WITHIN EACH INSTRUCTIONAL GROUP

	Group I		Group II		Group III	
	Pre	Post #1	Pre	Post #1	Pre	Post #1
H	30	39	23	34	36	37
Q ₃	19	28	17.5	26	22.5	26
Med	17	25	15	22	18	23
Q ₁	13.5	22	13	18	15.5	20
L	9	12	5	10	10	14
<hr/>						
\bar{X}	17.21	25.21	15.72	21.68	19.21	23.75
SD	4.49	5.37	3.85	5.01	5.27	5.05
N	57	57	57	57	57	57
<hr/>						
t	13.27		11.95		9.45	

$$t_{.01} (56df) = 2.67$$

$$t_{.001} (56df) = 3.48$$

TABLE II-A

ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES
BY THE THREE INSTRUCTIONAL GROUPS

Source of Variation	df	Sum of Squares	Mean Square	F
Between groups	2	344.88	172.44	10.82
Within groups	168	2677.86	15.94	
Total	170	3022.74		

$$F_{.01} (2df, 168df) = 4.73$$

$$F_{.001} (2df, 168df) = 7.2$$

In order to further isolate the effects of instructional treatment upon concept learning, Tables II-B, C, and D display secondary analyses of variance comparing pairs of instructional treatment groups. Although secondary analyses must be interpreted with special care since a more rigorous basis than usual is required for rejection of the null hypothesis, these secondary analyses do show that differences between all pairs of groups were significant.

TABLE II-B

ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES
BY GROUPS I AND III

Source of Variation	df	Sum of Squares	Mean Square	F
Between groups	1	340.43	340.43	20.09
Within groups	112	1898.14	16.95	
Total	113	2238.57		

$$F_{.01} (1df, 112df) = 6.87$$

$$F_{.001} (1df, 112df) = 11.4$$

TABLE II-C

ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES
BY GROUPS I AND II

Source of Variation	df	Sum of Squares	Mean Square	F
Between groups	1	122.14	122.14	7.05
Within groups	112	1939.72	17.32	
Total	113	2061.86		

$$F_{.01} (1df, 112df) = 6.87$$

$$F_{.001} (1df, 112df) = 11.4$$

TABLE II-D

ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES
BY GROUPS II AND III

Source of Variation	df	Sum of Squares	Mean Square	F
Between groups	1	54.75	54.75	4.04
Within groups	112	1517.86	13.55	
Total	113	1572.61		

$F_{.05} (1df, 112df) = 3.93$

$F_{.01} (1df, 112df) = 6.87$

2. Which of the three instructional treatments produced greatest efficiency of learning (gain in achievement per unit time)?

Table III displays a list of the mean time which students in the three instructional groups spent in unit activities, exclusive of time used for testing. Students in Group I spent a minimum of one hour and forty minutes at the computer terminals. No homework was done as part of the unit by students in this group. Group II classes spent six forty-minute periods on unit activities in class and approximately forty-five minutes were spent by each student in activities which were completed outside of class. Group III classes spent between nine and eleven fifty-minute periods in the unit and completed approximately twenty to thirty minutes of homework outside of class for each of these periods. In other words, Group III students spent approximately two full weeks in physics class on unit activities exclusive of test time.

TABLE III
TIME IN INSTRUCTIONAL ACTIVITIES

Group	Mean Time in Unit (minutes)	Group time + Group I time	Group time + Group III time
I	90	1.0	0.12
II	285	3.2	0.38
III	745	8.3	1.0

The two columns at the right side of Table III compare mean completion time for each instructional group with the mean completion time for Group I and Group III respectively. For example, on the average, Group III students worked in unit activities 8.3 times as long as students in Group I. Had concept learning been equivalent in all groups, then Groups I and II would have been 8.3 and 3.2 times more efficient respectively than Group III (control). However, concept learning was not equivalent. Information has already been presented indicating that Group I students achieved significantly higher gains during the instructional unit than did students in Group III. This means that the efficiency of learning in Group I was substantially greater than 8.3 to 1 when compared with learning in Group III. (Group II students fell between those in Groups I and III in both achievement and in time spent in instructional activities.)

3. What were the effects of the three instructional treatments upon retention?

The mean scores on Posttests #1 and #2 and the respective standard deviations for each instructional group are displayed in Table IV. It should be noted that Table IV includes only the scores of those students presented in Table I who also took Posttest #2. (Since Posttest #2 was administered late in the school year, some students in the study were not available to take that test.)

TABLE IV
POSTTEST #1 - POSTTEST #2 COMPARISON
WITHIN EACH INSTRUCTIONAL GROUP

Group	Test	Number of Students	Standard Deviation	Mean Test Score	t
I	Post #1	51	5.27	25.29	1.58
	Post #2	51	5.46	24.49	
II	Post #1	41	4.98	22.42	4.49
	Post #2	41	4.62	20.20	
III	Post #1	54	5.06	23.57	0.65
	Post #2	54	5.75	23.89	

$$t_{.05} (40-60df) = 2.0$$

After analyzing the data using a Related t test for paired variables, Table IV shows that the null hypothesis was not rejected for Group I and Group III, i.e., a significant loss in knowledge during the six month period after the unit was not measured by the tests administered to these groups. Table IV shows that there was a significant drop in score from Posttest #1 to Posttest #2 for the students in Group II.

Table V displays a review of Pretest and Posttest #2 scores. The table shows that the null hypothesis was rejected for each of the three instructional groups. Thus, the gains in concept learning made by all instructional groups were still significant six months after completion of the unit.

TABLE V
PRETEST - POSTTEST #2 COMPARISON
WITHIN EACH INSTRUCTIONAL GROUP

Group	Test	Number of Students	Standard Deviation	Mean Test Score	t
I	Pre	51	4.24	17.41	12.55
	Post #2	51	5.46	24.49	
II	Pre	41	3.55	16.02	9.48
	Post #2	41	4.62	20.20	
III	Pre	54	5.08	18.87	9.48
	Post #2	54	5.75	23.89	

$$t_{.001} (40-60df) = 3.5$$

4. How did the input variables of initial student intelligence, aptitude, grade level, and sex affect achievement?

To assess the effects of learner characteristics upon concept learning under the three instructional treatments, two way analyses of variance were run with Pretest - Posttest #1 difference scores for individual students as the dependent variable. Table VI summarizes the results of the analyses for six independent variables representing learner characteristics.

TABLE VI

TWO-WAY ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES
BY VARIABLE AND INSTRUCTIONAL GROUP -- SUMMARY

VARIABLE	I - III	Groups Compared	
		I - II	II - III
IQ	0	0	0
VPSAT	0	0	0
VPSAT interaction with instructional method	0	c	c
MPSAT	0	0	0
Pretest	b	0	b
Grade	0	0	0
Sex	c	c	0

b = H_0 rejected at .01 level.

c = H_0 rejected at .05 level.

0 = H_0 not rejected.

The table shows that IQ, VPSAT, MPSAT, and Grade did not significantly affect the concept learning which occurred during the instructional unit as measured by the evaluation instruments used in the study. Between Groups I and II and Groups II and III some interaction was observed between verbal aptitude and instructional method. Group II students having high verbal scores had substantially greater difference scores from Pretest to Posttest #1 than did students with lower verbal aptitude, and this phenomenon was not apparent in Group I or in Group III. From this data we might infer that reading ability was a greater factor contributing to achievement in Group II than in the other two instructional groups. It should be noted,

however, that the Group II high verbal cell size was considerably smaller than the corresponding cells in the other two groups.

Table VI indicates that Pretest score did significantly affect concept learning when Group I was compared with Group III and when Group II was compared with Group III. With the exception of an inversion in Group III, mean Pretest-Posttest #1 difference scores were greater when mean Pretest scores were lower in all instructional groups. Concept learning means from Pretest to Posttest #1 were lower for the girls than for the boys in all instructional groups. Table VI indicates that secondary analyses of variance showed that Sex did significantly affect concept learning when Group I was compared with Group III and when Group I was compared with Group II.

5. What effect did the unit have upon student attitude in the two instructional treatment groups using simulated materials?

A mean attitude score was developed for each student from responses on the Attitude Survey which was administered to students in Groups I and II six months after the conclusion of the instructional unit, and correlations between these scores and other variables were investigated. The grand mean scores on the survey for both groups indicated generally favorable attitudes toward the mode of instruction; the Group I mean was slightly higher than the Group II mean. A review of individual item means for each group is presented in Table VII. A score of five represents maximum favorable attitude, a score of one represents maximum negative attitude, and a score of three represents a neutral attitude toward the instructional unit. Responses should be

TABLE VII
INSTRUCTIONAL GROUP ATTITUDE PROFILES

Item and Description	Item and Description
Scale Values	Scale Values
1. Work at own pace	13. Conversational
2. -Not too mechanical	14. Learn quickly
3. -Easy to work	15. -Cared
4. -Didn't feel tense	16. Private tutor
5. -Didn't feel isolated	17. Personal attention
6. Responses helpful	18. Enjoyed
7. Efficient use of time	19. -Self-expression
8. -Pace not frustrating	20. Prefer format
9. -Not boring	
10. -Did not de-personalize	Grand Mean
11. Wanted to learn more	
12. -Method was flexible	

- Reversed Scales

X Group I mean

O Group II mean

carefully scrutinized individually, but a review indicates, among other things, that students liked the instructional units (Group I higher than Group II) and that they felt the units were easy to use. Also, it is interesting to note that students in Group II perceived the unit as making more efficient use of their time than did students in Group I. Yet, cognitive data in the study showed the reverse to be true.

CONCLUSIONS

Analysis of data in this study showed that student learning of fundamental concepts in force and motion was significant in the two experimental groups and in the control group. It also showed that learning was significantly greater for students studying the concepts through computer simulation dialogs than for students in the second experimental group and in the control group. Furthermore, control students spent 8.3 times as long in instructional unit activities.

Students in the control group spent 3.2 times as long in instructional activities as did students in a second simulation group which did not have access to the computer dialogs. The achievement of this second group was significantly greater than that of the control group. This simulation group, however, had conceptual losses not experienced by the control group as measured on a second posttest administered six months after the completion of the instructional unit. (Students using the computer simulation dialogs showed no significant losses in conceptual understanding as measured on the second posttest.)

Student attitudes toward both simulated units were favorable.

The data indicated that in spite of limitations, the computer does have extensive potential for individualizing instruction. The design of the instructional materials produced in this study may well provide a model for the design of other simulated experiments which will be effective supplements to science curricula.

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

PROGRAM AND FILE LISTINGS

technical report 1

115t
FORCEA

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10 PRINT ""
20 FILES LUNFI
30 DIM A$(64),N(14,10)
40 MAT N=ZER
50 L=0
60 PRINT "WELCOME TO OUR SIMULATED PHYSICS LAB. THROUGH THIS SERIES OF"
70 PRINT "PROGRAMS AND FILM LOOPS WE WILL INVESTIGATE HOW"
80 PRINT "FORCE AFFECTS THE MOTION OF AN OBJECT."
90 PRINT "HAVE YOU WATCHED THE FILM LOOP FORCE & MOTION 1?"
100 PRINT
110 PRINT "USE ONLY NUMERALS AND CAPS FOR ANSWERS"
120 PRINT
130 INPUT A$
140 Z=1
150 GOSUB 1350
160 READ #1,1
170 FOR I=1 TO 13
180 READ #1;A$
190 PRINT A$
200 NEXT I
210 PRINT "IF A ROCK IS TRAVELLING THROUGH SPACE AT 100 M/SEC AND THERE ARE NO"
220 PRINT "FORCES ACTING ON IT, WHAT WILL BE ITS SPEED (IN M/SEC) 5 SEC. LATER?"
230 INPUT D
240 IF D<100 THEN 1520
250 READ #1,14
260 FOR I=1 TO 9
270 READ #1;A$
280 PRINT A$
290 NEXT I
300 PRINT "TYPE BELOW THE AMOUNT OF STRETCH IN CM WHICH YOU INTEND TO APPLY DURING"
310 PRINT "THE RUNS THROUGHOUT THIS EXPERIMENT."
320 INPUT B
330 IF B<50 THEN 2570
340 IF B>100 THEN 2600
350 PRINT "YOU MAKE THE SIMULATED RUN WITH THE CART APPLYING A FORCE OF "B;"CM,"
360 PRINT "THEN I'LL ANALYZE THE TICKER TAPE, MAKE A DATA TABLE, AND PLOT A GRAPH"
370 PRINT "OF VELOCITY VERSUS TIME."
380 PRINT "HOW MANY BRICKS SHALL WE PLACE ON THE CART FOR A LOAD IN THIS RUN?"
390 INPUT C
400 IF C<1 THEN 2470
410 IF C>9 THEN 2530
420 IF C=INT(C) THEN 450
430 PRINT "WE DON'T HAVE PARTIAL BRICKS IN OUR LAB. TYPE IN A WHOLE NUMBER!"
440 GOTO 390
450 GOSUB 1030
460 PRINT "WHAT KIND OF RELATIONSHIP EXISTS BETWEEN VELOCITY AND TIME UNDER THESE"
470 PRINT "CONDITIONS (DIRECT OR INVERSE)?"
480 INPUT A$
490 IF A$="DIRECT" THEN 2370
500 READ #1,23
510 FOR I=1 TO 11
520 READ #1;A$
530 PRINT A$
540 NEXT I

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550 PRINT "FROM THE GRAPH WE CAN SEE THAT THE CONSTANT FORCE GAVE OUR"
560 PRINT "CART WHAT KIND OF ACCELERATION?"
570 INPUT A$
580 PRINT
590 IF A$="CONSTANT" THEN 1700
600 LET L=0
610 GOSUB 1260
620 PRINT "BUT IS THE ACCELERATION ALWAYS CONSTANT UNDER THE INFLUENCE OF A"
630 PRINT "CONSTANT FORCE?"
640 PRINT "HOW WOULD THE DATA DIFFER IF WE HAD USED A DIFFERENT LOAD?"
650 PRINT "TO FIND OUT, LET'S CHANGE THE NUMBER OF BRICKS ON THE CART AND MAKE"
660 PRINT "ANOTHER RUN APPLYING THE SAME FORCE OF";B;" CM."
670 PRINT "HOW MANY BRICKS SHALL WE PLACE ON THE CART FOR A LOAD IN THIS RUN?"
680 LET I=2
690 INPUT D
700 IF D<1 THEN 2470
710 IF D>9 THEN 2530
720 IF D=C THEN 2130
730 IF D=INT(D) THEN 760
740 PRINT "WE DON'T HAVE PARTIAL BRICKS IN OUR LAB. TYPE IN A WHOLE NUMBER!"
750 GOTO 690
760 LET C=D
770 MAT N=ZER
780 GOSUB 1030
790 GOSUB 1260
800 PRINT "AS YOU CAN SEE OUR DATA ALSO INDICATE THAT THE MASS OF THE CART DID"
810 PRINT "AFFECT THE ACCELERATION."
820 PRINT "WAS THE ACCELERATION GREATER OR SMALLER WHEN THE SMALLER MASS WAS"
830 PRINT "ACCELERATED?"
840 INPUT A$
850 IF A$="GREATER" THEN 1950
860 READ #1,34
870 FOR I=1 TO 9
880 READ #1;A$
890 PRINT A$
900 NEXT I
910 LET L=0
920 PRINT "IF AN AIRPLANE'S ENGINES PRODUCE A NET FORCE WHICH IS CONSTANT AND WHICH"
930 PRINT "ACCELERATES THE PLANE FROM 0 TO 100 M/SEC IN 20 SEC, WHAT WILL BE THE"
940 PRINT "PLANE'S VELOCITY IN M/SEC AT THE END OF 40 SEC?"
950 INPUT D
960 IF D#200 THEN 2020
970 PRINT "RIGHT! AGAIN, A CONSTANT FORCE CAUSES A MASS TO HAVE A CONSTANT"
980 PRINT "ACCELERATION."
990 PRINT "BUT HOW WOULD THE ACCELERATION HAVE DIFFERED HAD WE APPLIED A DIFFERENT"
1000 PRINT "FORCE?--THIS QUESTION WILL FORM THE BASIS FOR THE NEXT"
1010 PRINT "EXPERIMENT IN THIS SERIES."
1020 GOTO 2640
1030 PRINT "I'VE GOT THE BUZZER ON; --- AND THERE YOU GO PUSHING THE CART DOWN THE"
1040 PRINT "HALL FLEET-FOOTED AS A DEER!! ???"
1050 LET A=4*B/((C+1)*5)
1060 LET A=INT(10*A)/10
1070 PRINT "HERE IS A DATA TABLE I'VE MADE FROM THE TICKER TAPE PULLED BY THE"
1080 PRINT "CART IN THIS RUN:"
1090 PRINT
1100 PRINT "TIME (SEC)  VELOCITY (CM/SEC)  [LOAD =";C;" BRICKS  FORCE =";B;" CM]"
1110 FOR T=.1 TO 1 STEP .1

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1120 PRINT TAB(3);T;TAB(16);A*T
1130 LET V=A*T+1
1140 IF V<13.5 THEN 1160
1150 LET V=14
1160 LET N(V,T*10)=1
1170 NEXT T
1180 PRINT
1190 PRINT "HERE IS A GRAPH OF THE DATA:"
1200 GOSUB 2160
1210 PRINT "STUDY THE DATA AND GRAPH. CAN YOU OBSERVE ANY REGULARITIES?"
1220 INPUT A$
1230 Z=2
1240 GOSUB 1350
1250 RETURN
1260 PRINT "THE CONSTANT FORCE WE APPLIED IN THIS RUN DID PRODUCE A CONSTANT"
1270 PRINT "ACCELERATION."
1280 PRINT "ANALYZE THE GRAPH AND DETERMINE THE ACCELERATION IN CM/SEC/SEC."
1290 INPUT D
1300 IF (D >= A+.5) OR (D <= A-.5) THEN 1790
1310 PRINT "OK. OUR CONSTANT FORCE OF";B;"CM CAUSED OUR CART TO HAVE A CONSTANT"
1320 PRINT "ACCELERATION OF";A;" CM/SEC/SEC."
1330 PRINT
1340 RETURN
1350 IF A$="YES" THEN 1410
1360 IF A$="yes" THEN 1410
1370 IF A$="no" THEN 1470
1380 IF A$="NO" THEN 1470
1390 PRINT "PLEASE TYPE YES OR NO"
1400 GOTO Z OF 90,1210
1410 GOTO Z OF 160,1250
1420 PRINT "CALL PROCTOR - ERROR IN LINE 1296"
1430 GOTO 2690
1440 RETURN
1450 PRINT "PLEASE TYPE IN 'YES' OR 'NO'; I'LL ASK THE QUESTION AGAIN."
1460 GOTO 90
1470 IF Z=2 THEN 1670
1480 PRINT "TO MAKE THE SIMULATION AS REALISTIC AS POSSIBLE YOU SHOULD VIEW FILM"
1490 PRINT "LOOP FORCE & MOTION 1 PRIOR TO PROCEEDING. THE FILM WILL HELP YOU"
1500 PRINT "UNDERSTAND THE NATURE OF THE APPARATUS WE WILL USE."
1510 GOTO 2690
1520 IF D#0 THEN 1550
1530 PRINT "BE CAREFUL TO TYPE NUMBERS - TRY AGAIN"
1540 GOTO 230
1550 LET L=L+1
1560 IF L=2 THEN 1630
1570 READ #1,43
1580 FOR I=1 TO 6
1590 READ #1,A$
1600 PRINT A$
1610 NEXT I
1620 GOTO 210
1630 PRINT "NO; APPARENTLY YOU NEED TO REVIEW THE PROPERTY OF INERTIA (NEWTON'S 1ST"
1640 PRINT "LAW) BEFORE CONTINUING. CONSULT YOUR TEACHER OR YOUR TEXT AS SOON AS"
1650 PRINT "POSSIBLE."
1660 GOTO 2690
1670 PRINT "LOOK AT THE GRAPH AGAIN. THE PLOTTED POINTS SHOW THAT AS TIME INCREASED"

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1650 PRINT "THE VELOCITY INCREASED IN A RATHER SIMPLE MANNER."
1660 GOTO 1250
1700 IF A$="constant" THEN 600
1710 IF A$="UNIFORM" THEN 600
1720 IF A$="uniform" THEN 600
1730 READ #1,49
1740 FOR I=1 TO 8
1750 READ #1,A$
1760 PRINT A$
1770 NEXT I
1780 GOTO 550
1790 LET L=L+1
1800 IF L >= 3 THEN 1920
1810 IF L=2 THEN 1860
1820 PRINT "SORRY, YOUR CALCULATION IS INCORRECT. I'LL GIVE YOU ANOTHER CHANCE."
1830 PRINT "REMEMBER ACCELERATION IS THE SLOPE OF THE VELOCITY V.TIME GRAPH;"
1840 PRINT "SLOPE = RISE/RUN = CHANGE IN V/CHANGE IN T."
1850 GOTO 1280
1860 PRINT "YOU'RE NOT MEASURING THE SLOPE PROPERLY. STUDY THE GRAPH AND CALCULATE"
1870 PRINT "A AGAIN. IT SHOULD EQUAL"1A;"CM/SEC/SEC. TYPE 'GO' IF YOU SEE HOW TO GE
1880 PRINT "THIS AND YOU WANT TO RETURN TO THE EXPERIMENT, OTHERWISE TYPE 'HELP'."
1890 INPUT A$
1900 IF A$="GO" THEN 1340
1910 IF A$="go" THEN 1340
1920 PRINT "YOU NEED ASSISTANCE IN MEASURING THE SLOPE OF A STRAIGHT"
1930 PRINT "LINE. SEE YOUR TEACHER FOR HELP BEFORE RETURNING TO THIS PROGRAM."
1940 GOTO 2690
1950 IF A$="LARGER" THEN 860
1960 IF A$="greater" THEN 860
1970 IF A$="larger" THEN 860
1980 PRINT "NO. LOOK AT YOUR GRAPHS AGAIN. THE ACCELERATIONS ARE REPRESENTED BY THE
1990 PRINT "SLOPES OF THE VELOCITY V. TIME GRAPHS. THE LARGER MASS HAS THE SMALLER"
2000 PRINT "ACCELERATION! LET'S TRY THE QUESTION AGAIN."
2010 GOTO 820
2020 IF L >= 2 THEN 2100
2030 LET L=L+1
2040 PRINT "NO. SINCE A CONSTANT NET FORCE IS PRESENT THE PLANE WILL UNDERGO A"
2050 PRINT "CONSTANT ACCELERATION. THE SAME CHANGE IN VELOCITY WILL OCCUR IN EACH"
2060 PRINT "TIME INTERVAL.FROM THE DATA IN THE PROBLEM WE CAN SEE THAT THE PLANE'S"
2070 PRINT "VELOCITY INCREASES BY 5M/SEC EACH SEC.WHILE THE NET FORCE IS PRESENT."
2080 PRINT "LET'S TRY THE QUESTION AGAIN."
2090 GOTO 920
2100 PRINT "NO. THE CORRECT ANSWER IS 200M/SEC. IF YOU DON'T UNDERSTAND WHY DISCUSS
2110 PRINT "THIS WITH YOUR TEACHER AS SOON AS POSSIBLE."
2120 GOTO 920
2130 PRINT "NO; DON'T USE";D;" BRICKS AGAIN. WE WANT TO MAKE A RUN WITH A LOAD"
2140 PRINT "THAT IS DIFFERENT FROM OUR FIRST RUN. SO, AGAIN--"
2150 GOTO 670
2160 PRINT
2170 FOR Y=12 TO 1 STEP -1
2180 READ A$
2190 PRINT A$;
2200 IF Y/2<INT(Y/2) THEN 2220
2210 PRINT TAB(7);Y;
2220 FOR X=1 TO 10
2230 IF NC(Y+1,X)=1 THEN 2270

```



ERIC
Full Text Provided by ERIC

1

ONE INSTRUCTION BEFORE WE BEGIN: WHEN YOU'RE ASKED TO TYPE
2
IN NUMERICAL DATA, DO NOT TYPE THE UNITS OF THE ANSWER. FOR
3
EXAMPLE, AN ANSWER OF 10M/SEC SHOULD BE TYPED '10'.

4

EXPERIENCE TELLS US THAT WE MUST APPLY A FORCE TO CAUSE
5
AN OBJECT TO MOVE. IN THIS SERIES OF SIMULATED EXPERIMENTS WE
6
SHALL INVESTIGATE PHYSICAL VARIABLES WHICH AFFECT THE MOTION
7
OF AN OBJECT. THE DATA WHICH WE WILL GENERATE WILL BE VERY
8
SIMILAR TO THAT OBTAINED BY EXPERIMENTERS USING THE REAL
9
APPARATUS SHOWN IN THE FILM LOOP. I WILL BE YOUR LAB
10
PARTNER.

11

BEFORE WE CONTINUE, YOU SHOULD BE FAMILIAR WITH THE
12
PROPERTY OF INERTIA WHICH WAS DESCRIBED BY GALILEO AND
13
NEWTON.

14

CORRECT! DUE TO THE PROPERTY OF INERTIA (SOMETIMES CALLED
15
NEWTON'S 1ST LAW) AN OBJECT'S VELOCITY WILL BE CONSTANT
16
UNTIL AN UNBALANCED FORCE IS APPLIED. YET, IN WHAT WAY WILL
17
AN UNBALANCED FORCE CAUSE THE VELOCITY TO CHANGE?

18

IN THIS FIRST EXPERIMENT WE SHALL INVESTIGATE HOW AN
19
OBJECT'S VELOCITY CHANGES WHEN WE APPLY A CONSTANT FORCE.
20
WE SHALL APPLY A CONSTANT FORCE TO THE CART BY KEEPING ONE
21
LOOP OF RUBBER STRETCHED A CONSTANT LENGTH. (WE CAN
22
STRETCH OUR LOOP TO ANY LENGTH BETWEEN 50CM AND 100CM.)

23

RIGHT! IN FACT, THERE APPEARS TO BE A LINEAR RELATIONSHIP
24
BETWEEN VELOCITY AND TIME IF WE OVERLOOK THE SMALL IRREGU-

25
LARITIES PROBABLY CAUSED BY EXPERIMENTAL ERROR -- SUCH AS
26
VARIATIONS IN THE FORCE APPLIED. THE CHANGE IN VELOCITY WAS
27
PROPORTIONAL TO THE TIME INTERVAL DURING WHICH THE FORCE
28
ACTED. WHEN WE APPLIED A CONSTANT FORCE TO THE CART THE
29
VELOCITY INCREASED AT A CONSTANT RATE.

30
FROM YOUR STUDY OF MOTION YOU WILL RECALL THAT ACCELE-
31
TION IS THE RATE OF CHANGE OF VELOCITY. THE ACCELERATION
32
OF AN OBJECT IS THEN THE SLOPE OF ITS VELOCITY V. TIME
33
GRAPH. (CHANGE IN V/CHANGE IN T).
34

CORRECT; THE SMALLER MASS UNDERWENT A LARGER ACCELERATION.
35
APPARENTLY THERE IS SOME KIND OF INVERSE RELATIONSHIP
36
BETWEEN THE MASS OF AN OBJECT AND ITS ACCELERATION WHEN A
37
CONSTANT FORCE IS APPLIED. WE WILL FURTHER INVESTIGATE THIS
38
RELATIONSHIP IN THE THIRD EXPERIMENT IN THIS SERIES.

39
TO SUMMARIZE: WE CAN SEE FROM THE GRAPHS OF OUR DATA THAT
40
WHEN A CONSTANT FORCE WAS APPLIED TO A CART WITH A PARTI-
41
CULAR MASS THE ACCELERATION WAS CONSTANT.
42

NOW, LET'S TRY ONE LAST PROBLEM.
43

NO; YOUR ANSWER IS INCORRECT. BY THE PROPERTY OF INERTIA WE
44
MEAN THAT AN UNBALANCED FORCE IS NECESSARY TO CHANGE THE
45
VELOCITY OF AN OBJECT. IN THIS PROBLEM WE WERE TOLD THAT NO
46
FORCES WERE ACTING, AND HENCE, NO CHANGE IN VELOCITY WILL
47
OCCUR. APPARENTLY EVEN FRICTION IS NEGLIGIBLE IN THIS
48
PROBLEM. I'LL ASK THE QUESTION ONE MORE TIME.
49

INCORRECT. THIS GRAPH OF VELOCITY VS. TIME CAN BE REPRESENTED
50
BY A STRAIGHT LINE. THE SLOPE OF A STRAIGHT LINE IS THE SAME

51
AT ALL POINTS ON THE LINE. AN OBJECT'S ACCELERATION IS ITS
52
CHANGE IN VELOCITY PER UNIT TIME; IT IS THE SLOPE OF THE
53
VELOCITY V. TIME GRAPH. THEREFORE THE CONSTANT FORCE HAS
54
CAUSED A CONSTANT ACCELERATION. IF YOU HAVE DIFFICULTY
55
UNDERSTANDING THESE IDEAS, DO TALK THEM OVER WITH YOUR
56
TEACHER AS SOON AS POSSIBLE. LET'S TRY THE QUESTION AGAIN--
57

SINCE YOU HAVE BEEN STUDYING FORCE AND MOTION USING A SIMU-
58
LATED EXPERIMENT, YOU HAVE NOT HAD TO COPE WITH THE MANY
59
SOURCES OF EXPERIMENTAL ERROR PRESENT IN THE ACTUAL
60
APPARATUS. IF YOU WERE TO DO THE REAL EXPERIMENT YOU WOULD
61
HAVE TO REDUCE SUCH ERROR BEFORE THE GENERALIZATIONS WE'VE
62
SEEN COULD BE OBSERVED. PERHAPS YOU WILL BE ABLE TO PURSUE
63
THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB.
64
AFTER YOU'VE SIGNED OFF THE TERMINAL ROLL OUT SEVERAL
65
EXTRA INCHES OF PAPER. ON THIS PAPER LIST THE SOURCES OF
66
EXPERIMENTAL ERROR AS YOU ENVISION THEM AND STATE THE
67
MAJOR CONCLUSIONS YOU CAN DRAW FROM THE EXPERIMENT.
68
INCLUDE THIS PAPER IN YOUR PHYSICS NOTEBOOK. AS SOON AS
69
YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM LOOP 'FORCE &
70
MOTION II' AND THEN RUN 'FORCEB'.
71

72

73

74

list
FORCES

```

10  FILES LUNF2
20  DIM A$(65),N$(11,10),O$(11,10)
30  PRINT "WELCOME AGAIN TO OUR SIMULATED PHYSICS LAB. IN THIS SECOND"
40  PRINT "EXPERIMENT OF THE SERIES WE WILL INVESTIGATE HOW FORCES AFFECT"
50  PRINT "THE ACCELERATION OF AN OBJECT. HAVE YOU COMPLETED FORCEA &"
60  PRINT "WATCHED THE FILM LOOP 'FORCE & MOTION II'?"
70  INPUT A$
80  IF A$="YES" THEN 90
82  IF A$#"yes" THEN 2760
90  LET L=0
95  MAT N=ZER
95  MAT O=ZER
100 PRINT "IN OUR LAST EXPERIMENT WE OBSERVED THAT A CONSTANT FORCE GAVE OUR CART"
110 PRINT "WHAT KIND OF ACCELERATION?"
120 INPUT A$
130 IF A$="CONSTANT" THEN 150
132 IF A$="constant" THEN 150
134 IF A$="uniform" THEN 150
140 IF A$#"UNIFORM" THEN 2800
150 PRINT "RIGHT! NOW TO STUDY HOW ACCELERATION VARIES WHEN THE APPLIED FORCE IS"
160 PRINT "CHANGED WE'LL HOLD ALL OTHER VARIABLES (SUCH AS MASS) CONSTANT."

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```

170 PRINT "HOW MANY BRICKS SHALL WE PLACE ON THE CART THROUGHOUT THIS EXPERIMENT?"
180 INPUT C
190 IF C<2 THEN 2660
200 IF C>10 THEN 2720
210 LET M=(C+1)*5
220 LET F=2.5
230 IF C>9 THEN 310
240 LET F=2
250 IF C>7 THEN 310
260 LET F=1.5
270 IF C>5 THEN 310
280 LET F=1
290 IF C>3 THEN 310
300 LET F=.5
310 READ #1,I
320 FOR I=1 TO 7
330 READ #1;A$
340 PRINT A$
350 NEXT I
360 FOR L=1 TO 11
370 PRINT "HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?"
380 INPUT B
390 IF B=INT(B) THEN 420
400 PRINT "WE DON'T HAVE ANY PARTIAL LOOPS IN OUR LAB. TYPE IN A WHOLE NUMBER."
410 GOTO 380
420 IF B<0 THEN 1470
430 IF B>10 THEN 1500
440 LET A1=240*(B-F)/M
450 LET A1=INT(10*A1+.5)/10
460 LET A2=240*B/M
470 LET A2=INT(10*A2+.5)/10
480 IF A1>0 THEN 500
490 LET A1=0
500 PRINT "THE ACCELERATION IN THIS RUN WAS: ";A1;" CM/SEC/SEC."
510 IF A2 >= 105 THEN 560
520 IF A1 >= 105 THEN 560
530 IF B=0 THEN 560
540 LET N(A1/10+1,B)=1
550 LET O(A2/10+1,B)=1
560 IF L<5 THEN 620
570 PRINT "IF YOU'D LIKE TO MAKE ANOTHER RUN, TYPE 'RUN'; IF YOU'D LIKE ME"
580 PRINT "TO GRAPH A VS. F, TYPE 'PLOT'."
590 INPUT A$
595 IF A$="plot" THEN 630
600 IF A$="PLOT" THEN 630
605 IF A$="run" THEN 620
610 IF A$="RUN" THEN 1540
620 NEXT L
630 GOSUB 2180
640 PRINT "CAN YOU OBSERVE ANY REGULARITIES IN THIS GRAPH?"
650 INPUT A$
655 IF A$="yes" THEN 670
660 IF A$/"YES" THEN 1560

```

```

670 PRINT "WHAT KIND OF RELATIONSHIP EXISTS BETWEEN ACCELERATION AND FORCE "
680 PRINT "(DIRECT OR INVERSE)?"
690 INPUT AS
695 IF AS="direct" THEN 710
700 IF AS/"DIRECT" THEN 2570
710 READ #1,8
720 FOR I=1 TO 6
730 READ #1;AS
740 PRINT AS
750 NEXT I
760 INPUT AS
770 LET L=0
780 PRINT "THERE IS FRICTION BETWEEN THE CART AND THE FLOOR WHICH OPPOSES THE"
790 PRINT "FORCE WE APPLY. STUDY THE GRAPH & DETERMINE THE FORCE OF"
800 PRINT "FRICTION(IN LOOPS).-"
810 INPUT D
820 IF D<(F-.5) THEN 1620
830 IF D>(F+.5) THEN 1620
840 READ #1,15
850 FOR I=1 TO 5
860 READ #1;AS
870 PRINT AS
880 NEXT I
890 INPUT AS
895 IF AS="left" THEN 1750
900 IF AS="LEFT" THEN 1750
905 IF AS="right" THEN 920
910 IF AS/"RIGHT" THEN 1810
920 READ #1,20
930 FOR I=1 TO 4
940 READ #1;AS
950 PRINT AS
960 NEXT I
970 LET L=0
980 PRINT "TYPE IN THE POINT WHERE YOU THINK THE NEW PLOT WILL INTERSECT THE"
990 PRINT "FORCE AXIS."
1000 INPUT D
1010 IF D#0 THEN 1830
1020 PRINT "RIGHT! HERE'S THE NEW GRAPH: "
1030 MAT N=0
1040 GOSUB 2180
1050 PRINT "AGAIN, WE SEE A LINEAR RELATIONSHIP BETWEEN FORCE AND ACCELE-"
1060 PRINT "RATION. NOTE THAT THOUGH THE INTERCEPT WITH THE FORCE AXIS"
1070 PRINT "HAS BEEN MOVED, THE SLOPE OF THE GRAPH HAS NOT CHANGED. "
1080 PRINT "FRICTIONAL FORCE DOES NOT APPEAR TO AFFECT THE SLOPE OF THE"
1090 PRINT "ACCEL. VS. FORCE GRAPH."
1100 LET L=0
1110 PRINT "WRITE AN EQUATION TO FIT THIS GRAPH. USE 'A' TO REPRESENT ACCELERATION"
1120 PRINT "AND 'F' TO REPRESENT FORCE. USE 'K' TO REPRESENT THE SLOPE (DON'T"
1130 PRINT "BOTHER TO CALCULATE IT). BEGIN THE EQUATION: A= ..."
1140 INPUT AS
1145 IF AS="a=Kf" THEN 1160
1150 IF AS/"A=KF" THEN 2400

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```

1160 PRINT "RIGHT!--BUT WHAT FACTORS WILL CAUSE THE SLOPE TO CHANGE? WE'VE"
1170 PRINT "OBSERVED THAT FRICTION HAS NO EFFECT. WHAT OTHER VARIABLE"
1180 PRINT "MIGHT CAUSE THE SLOPE TO CHANGE?"
1190 INPUT AS
1195 IF AS="mass" THEN 1210
1200 IF AS="MASS" THEN 1930
1210 READ #1,24
1220 FOR I=1 TO 10
1230 READ #1;AS
1240 PRINT AS
1250 NEXT I
1260 LET L=0
1270 PRINT "A SPACESHIP IS ACCELERATING IN SPACE AT 10M/SEC/SEC DUE TO THE FORCE"
1280 PRINT "PROVIDED BY ONE ROCKET ENGINE. SUDDENLY 2 MORE IDENTICAL ROCKETS ARE"
1290 PRINT "IGNITED PROVIDING THRUST IN THE SAME DIRECTION AS THE FIRST. WHAT"
1300 PRINT "ACCELERATION IN M/SEC/SEC DOES THE SHIP NOW EXPERIENCE?"
1310 INPUT D
1320 IF D#30 THEN 1950
1330 PRINT "GOOD! HERE'S ANOTHER PROBLEM FOR YOU TO TRY:"
1340 PRINT "IN 10 SEC AN OBJECT ACCELERATES FROM REST TO A SPEED OF 300CM/SEC"
1350 PRINT "WHEN ACTED UPON BY A NET FORCE(F). AT THE END OF THE 10SEC"
1360 PRINT "INTERVAL F BECOMES ONE-THIRD ITS ORIGINAL STRENGTH."
1370 PRINT "WHAT IS THE SPEED OF THE OBJECT AT THE END OF THE FIRST 20 SEC IN"
1380 PRINT "CM/SEC?"
1390 INPUT D
1400 IF D#400 THEN 2060
1410 READ #1,34
1420 FOR I=1 TO 11
1430 READ #1;AS
1440 PRINT AS
1450 NEXT I
1460 GOTO 2880
1470 PRINT "A NEGATIVE NUMBER OF LOOPS?? WE CAN ONLY APPLY POSITIVE"
1480 PRINT "FORCE WITH OUR APPARATUS. SO, AGAIN --"
1490 GOTO 370
1500 PRINT "WITH MORE THAN 10 LOOPS STRETCHED 60CM THE CART MOVES SO FAST"
1510 PRINT "YOU CAN'T APPLY A CONSTANT FORCE. DON'T USE MORE THAN 10"
1520 PRINT "LOOPS. SO, AGAIN --"
1530 GOTO 370
1540 PRINT "YOU DIDN'T TYPE 'PLOT' OR 'RUN'. WHICH DO YOU WANT TO DO?"
1550 GOTO 590
1560 PRINT "ARE YOU LOOKING CAREFULLY AT THE DATA?"
1570 PRINT "NOTICE THAT AS FORCE INCREASES, ACCELERATION"
1580 PRINT "ALSO INCREASES."
1590 GOTO 670
1600 IF L>1 THEN 1690
1610 LET L=L+1
1620 PRINT "SORRY, WRONG ANSWER. THE FORCES WE HAVE PLOTTED ARE THE FORCES"
1630 PRINT "WE APPLIED. FRICTION OPPOSES THE APPLIED FORCE. UNTIL THE"
1640 PRINT "APPLIED FORCE EXCEEDS FRICTION THERE WILL BE NO ACCELERATION."
1650 PRINT "FIND THAT POINT ON YOUR GRAPH. LET'S TRY THE QUESTION AGAIN."
1660 GOTO 810
1670 PRINT "NO. THE FRICTIONAL FORCE IS";F;" LOOPS. IT IS REPRESENTED"
1680 PRINT "BY THE INTERCEPT OF THE GRAPH WITH THE FORCE AXIS. IF YOU"

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1710 PRINT "DON'T UNDERSTAND DISCUSS THIS WITH YOUR TEACHER AS SOON"
1720 PRINT "AS POSSIBLE. NOW, ANSWER THE QUESTION CORRECTLY. WHAT IS THE FORCE OF"
1730 PRINT "FRICTION SHOWN ON THE GRAPH?"
1740 GOTO 810
1750 PRINT "THINK IT THROUGH AGAIN. THE"
1760 PRINT "MORE FRICTION, THE MORE FORCE"
1770 PRINT "REQUIRED TO CHANGE THE INTERCEPT."
1771 READ #1, I7
1772 FOR I=1 TO 3
1773 READ #1, IAS
1774 PRINT AS
1775 NEXT I
1800 GOTO 890
1810 PRINT "YOUR ANSWER MUST BE 'LEFT' OR 'RIGHT'. SO AGAIN --"
1820 GOTO 890
1830 IF L>1 THEN 1890
1840 LET L=L+1
1850 PRINT "NO. PLOTTING THE RESULTANT FORCE IS EQUIVALENT TO SUBTRACTING"
1860 PRINT "THE FRICTIONAL FORCE FROM THE APPLIED FORCE. THE GRAPH WILL"
1870 PRINT "REPRESENT A FRICTIONLESS CONDITION. TRY THE QUESTION AGAIN."
1880 GOTO 980
1890 PRINT "NO. THE NEW GRAPH SHOULD PASS THROUGH THE ORIGIN. IF YOU DON'T"
1900 PRINT "UNDERSTAND WHY, DISCUSS THIS WITH YOUR TEACHER AS SOON AS "
1910 PRINT "POSSIBLE. HERE'S THE NEW GRAPH."
1920 GOTO 1040
1930 PRINT "WHAT ABOUT THE MASS OF THE CART?"
1940 GOTO 1210
1950 IF L>1 THEN 2010
1960 LET L=L+1
1970 PRINT "WRONG. THE APPLIED FORCE INCREASED TO 3 TIMES ITS ORIGINAL"
1980 PRINT "VALUE. THE ACCELERATION OF THE SPACESHIP IS PROPORTIONAL TO"
1990 PRINT "THE APPLIED FORCE. TRY THE QUESTION AGAIN."
2000 GOTO 1270
2010 PRINT "SINCE THE FORCE INCREASED TO 3 TIMES ITS ORIGINAL VALUE, THE"
2020 PRINT "ACCEL. INCREASED TO 3 TIMES ITS ORIGINAL VALUE, AND  $3 \times 10 = 30$ ."
2030 PRINT "IF YOU DON'T UNDERSTAND DISCUSS THIS WITH YOUR TEACHER AS SOON"
2040 PRINT "AS POSSIBLE. NOW, HERE'S ANOTHER PROBLEM."
2050 GOTO 1340
2060 IF L>2 THEN 2140
2070 LET L=L+1
2080 PRINT "SORRY, WRONG ANSWER, IN THE SECOND TIME INTERVAL THE FORCE"
2090 PRINT "IS 1/3 ITS ORIGINAL VALUE AND HENCE THE ACCEL. IS 1/3 ITS"
2100 PRINT "ORIGINAL VALUE. IF THE OBJECT GAINED 300CM/SEC IN THE FIRST"
2110 PRINT "10 SEC, IT WILL GAIN 1/3 THAT IN THE NEXT 10 SEC. TRY THE"
2120 PRINT "QUESTION AGAIN."
2130 GOTO 1370
2140 PRINT "NO. 1/3 OF 300 IS 100. YOU NEED FURTHER HELP IN UNDERSTANDING"
2150 PRINT "THIS CONCEPT. CONSULT YOUR TEACHER BEFORE CONTINUING THIS"
2160 PRINT "PROGRAM."
2170 GOTO 2850
2180 PRINT
2190 FOR Y=10 TO 1 STEP -1
2200 READ AS
2210 PRINT AS

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0220 IF Y#2#INT(Y/2) THEN 2270
02230 IF Y#10 THEN 2260
02240 PRINT TAB(6); "-" * 10 * Y;
02250 GOTO 2270
02260 PRINT TAB(7); 10 * Y;
02270 FOR X=1 TO 10
02280 IF N(X+1,X)=1 THEN 2320
02290 NEXT X
02300 PRINT TAB(13); "+"
02310 GOTO 2330
02320 PRINT TAB(13); "+"; TAB(13+X*4); "X"
02330 NEXT Y
02340 PRINT TAB(9); "0 + + + + + + + + + + + + + + + +"
02350 PRINT TAB(13); "0 1 2 3 4 5 6 7 8 9 10"
02360 PRINT TAB(29); "FORCE (LOOPS)"
02370 DATA "-", "", "A", "C", "C", "E(CM/SEC/SEC)", "L.", "=", ",", "--"
02380 RESTORE
02390 RETURN
02400 IF AS="A*K*F" THEN 1160
02405 IF AS="a*k*f" THEN 1160
02410 IF AS="A*FK" THEN 1160
02415 IF AS="a*fK" THEN 1160
02420 IF AS="A*KXF" THEN 1160
02425 IF AS="a=kxf" THEN 1160
02430 IF AS="A*FXK" THEN 1160
02435 IF AS="a=fxk" THEN 1160
02440 IF AS="A=F*K" THEN 1160
02445 IF AS="a=f*k" THEN 1160
02450 IF L>1 THEN 2530
02460 LET L=L+1
02470 READ #1, A$
02480 FOR I=1 TO 7
02490 READ #1; A$
02500 PRINT A$
02510 NEXT I
02520 GOTO 1110
02530 PRINT "NO. THE EQUATION IS: A=KF. IF YOU DON'T UNDERSTAND"
02540 PRINT "WHY DISCUSS THIS WITH YOUR TEACHER AS SOON AS POSSIBLE."
02550 PRINT "NOW, HERE'S THE QUESTION ONCE MORE."
02560 GOTO 1110
02570 IF AS="INVERSE" THEN 2600
02575 IF AS="inverse" THEN 2600
02580 PRINT "YOUR ANSWER MUST BE 'DIRECT' OR 'INVERSE'. SO, AGAIN --"
02590 GOTO 670
02600 READ #1, A$
02610 FOR I=1 TO 4
02620 READ #1; A$
02630 PRINT A$
02640 NEXT I
02650 GOTO 670
02660 PRINT "THE EXPERIMENT MUST HAVE AT LEAST 2"
02670 PRINT "BRICKS ON THE CART."
02680 PRINT "SO, I'LL NEED ANOTHER NUMBER."
02710 GOTO 170
```

```
2720 PRINT "YOU'LL FIND THAT THE CART WILL BE VERY SLOW AND HARD TO HANDLE"
2730 PRINT "WITH MORE THAN 10 BRICKS ON IT. DON'T USE MORE THAN 10 BRICKS."
2740 PRINT "SO, AGAIN --"
2750 GOTO 170
2760 PRINT "THIS PROGRAM IS THE SECOND IN A SERIES. SINCE THE CONCEPTS"
2770 PRINT "DEVELOPED ARE SEQUENTIAL YOU SHOULD BEGIN BY VIEWING THE FILM"
2780 PRINT "LOOP 'FORCE & MOTION I', THEN RUN FORCEA."
2790 GOTO 2880
2800 IF L=0 THEN 2860
2810 LET L=L+1
2820 PRINT "YOU SHOULD KNOW THE CORRECT ANSWER TO THIS QUESTION IF YOU'VE"
2830 PRINT "BEEN THROUGH 'FORCEA'. I'LL GIVE YOU ONE MORE CHANCE TO"
2840 PRINT "TYPE IT PROPERLY."
2850 GOTO 100
2860 PRINT "RUN 'FORCEA' BEFORE CONTINUING."
2870 GOTO 2880
2880 PRINT "TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY"
2890 END
```

WHAT FILE IS TO BE LISTED?

71unf2

STARTING RECORD NUMBER?

71

1

AS YOU OBSERVED IN THE FILM, WE CAN VARY THE FORCE WE APPLY

2

BY USING DIFFERENT NUMBERS OF RUBBER LOOPS STRETCHED A CON-

3

STANT LENGTH; I SUGGEST 60 CM FOR ALL LOOPS IN THIS EXPERIMENT

4

YOU SPECIFY THE FORCE YOU'LL APPLY IN EACH TRIAL AND

5

MAKE THE SIMULATED RUN. THEN I'LL DETERMINE ACCELERATION

6

FROM THE TICKER TAPE AND PLOT A GRAPH OF ACCELERATION V.

7

FORCE WHEN WE HAVE ENOUGH DATA.

8

RIGHT! IN FACT, THERE APPEARS TO BE A LINEAR RELATIONSHIP

9

BETWEEN FORCE AND ACCELERATION IF WE OVERLOOK THE IRREGULARITIES

10

PROBABLY CAUSED BY EXPERIMENTAL ERROR.

11

NOTE THAT THE GRAPH DOES NOT PASS THROUGH THE ORIGIN.

12

APPARENTLY THE CART DOES NOT ACCELERATE WHEN WE APPLY A

13

SMALL POSITIVE FORCE. WHAT COULD CAUSE THIS?

14

COULD IT BE FRICTION?

15

FINE! THE FORCE OF FRICTION IS REPRESENTED BY THE INTERCEPT

16

OF THE GRAP WITH THE FORCE AXIS.

17

HAD WE USED A CART WITH GREATER FRICTION THAN IN OUR EXPERIMENT

18

WOULD THIS INTERCEPT BE TO THE RIGHT OR LEFT OF ITS

19

PRESENT LOCATION? (TYPE 'RIGHT' OR 'LEFT')

20

CORRECT! NEXT, I'M GOING TO TAKE THE DATA WE COLLECTED AND PLOT

21

THE RESULTANT FORCE ACTING ON THE CART, INSTEAD OF THE

22

FORCE YOU APPLIED IN EACH RUN. (THE RESULTANT OR NET FORCE

23

IS THE FORCE YOU APPLIED MINUS THE FORCE OF FRICTION.)

24

AS WE OBSERVED IN THE LAST EXPERIMENT, MASS HAS AN INVERSE

25

RELATIONSHIP TO ACCELERATION WHEN A CONSTANT FORCE IS

26

APPLIED. IN THE NEXT EXPERIMENT WE'LL CONDUCT A QUANTITATIVE

27

STUDY OF THIS RELATIONSHIP.

28

TO SUMMARIZE, WE CAN SEE FROM OUR DATA THAT ACCELERATION IS

29

DIRECTLY PROPORTIONAL TO THE NET FORCE WHEN THE MASS REMAINS

30

CONSTANT. THE EQUATION FOR THE RELATIONSHIP IS: $A=KF$. I

31

SHOULD EMPHASIZE THAT F REPRESENTS THE NET OR RESULTANT

32

FORCE; IT IS THE VECTOR SUM OF ALL FORCES ACTING ON THE

33

OBJECT. NOW, TRY THIS PROBLEM:

34

CORRECT!

35

YOU HAVE NOW COMPLETED THIS SIMULATED EXPERIMENT. PERHAPS

36

YOU WILL BE ABLE TO PURSUE THE INVESTIGATION FURTHER AT

37

HOME OR IN YOUR LAB.

38

AFTER YOU'VE SIGNED OFF THE TERMINAL, ROLL OUT SEVERAL

39

INCHES OF PAPER. ON IT LIST THE SOURCES OF EXPERIMENTAL

40

ERROR AS YOU ENVISION THEM AND STATE THE MAJOR CONCLUSIONS

41

YOU CAN DRAW FROM THE EXPERIMENT. INCLUDE THIS PAPER IN

42

YOUR PHYSICS NOTEBOOK.

43

AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM

44

LOOP 'FORCE & MOTION III', THEN RUN 'FORCEC'.

45

WRONG. THE GRAPH CAN BE REPRESENTED BY A STRAIGHT LINE

46

PASSING THROUGH THE ORIGIN. FROM YOUR WORK IN ALGEBRA

47

YOU KNOW THE EQUATION FOR A STRAIGHT LINE: $Y=MX+B$. (M

48

IS THE SLOPE AND B THE X-INTERCEPT.) IN THIS CASE, WE'RE

49

USING 'A' TO REPRESENT ACCELERATION ON THE VERTICAL AXIS

50

AND 'F' FOR THE FORCE ON THE HORIZONTAL AXIS. THE FORCE

51

INTERCEPT IS 0. TRY THE QUESTION AGAIN.

52

52 RECORDS IN FILE 1unf2

CEC

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FILES LUNF3
DIM ASC(20),RC(13,100),DC(13,100)
MAT R=ZER
MAT D=ZER
PRINT "HELLO AGAIN. IN THIS THIRD PART OF THE SERIES WE WILL STUDY HOW
PRINT "CONSTANT FORCE ACCELERATES DIFFERENT MASSES. HAVE YOU COMPLETED 'FORCEB'?"
PRINT "AND THEN VIEWED FILM LOOP 'FORCE & MOTION III'?"
INPUT A$
IF A$="YES" THEN 110
IF A$="yes" THEN 2710
PRINT "IN THE FIRST EXPERIMENT OF THIS SERIES WE OBSERVED THAT CONSTANT"
PRINT "FORCES CAUSE A BODY TO UNDERGO A CONSTANT ACCELERATION. IN THE "
PRINT "LAST EXPERIMENT WE HELD THE MASS CONSTANT AND OBSERVED WHAT KIND O
PRINT "RELATIONSHIP BETWEEN ACCELERATION AND FORCE?"
LET L=0
INPUT A$
IF A$="DIRECT" THEN 210
IF A$="direct" THEN 210
IF A$="LINEAR?" THEN 210
IF A$="LINEAR" THEN 2750
READ #1,1
FOR I=1 TO 5
  READ #1;A$
  PRINT A$
NEXT I
PRINT "TYPE BELOW THE AMOUNT OF STRETCH IN CM YOU WILL APPLY DURING THE"
PRINT "RUNS THROUGHOUT THIS EXPERIMENT."
INPUT B
IF B<50 THEN 2630
IF B>100 THEN 2670
READ #1,6
FOR I=1 TO 9
  READ #1;A$
  PRINT A$
NEXT I
FOR L=1 TO 12
  PRINT "HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?"
  INPUT C
  IF C<1 THEN 2550
  IF C>10 THEN 2600
  LET M=(C+1)*5
  LET A=INT(40*(2/M+.5)/10
  IF A>24 THEN 450
  LET H=(A/2+1,C)=1
  IF 50/A>12 THEN 470
  LET D=(50/A+1,C)=1
  PRINT "FOR YOUR TOTAL MASS OF";C+1;" BRICKS, THE ACCELERATION"
  PRINT "WAS:";A;" CM/SEC/SEC. [1/A=";INT(1000/A)/1000;" ]"
  IF C=5 THEN 570
  IF YOU'D LIKE TO MAKE ANOTHER RUN TYPE 'RUN'; IF YOU'D LIKE ME TO"

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```

510 PRINT "GRAPH A VERSUS M TYPE 'PLOT'."
520 INPUT A$
530 IF A$="PLOT" THEN 580
540 IF A$="plot" THEN 580
550 IF A$="RUN" THEN 570
560 IF A$="run" THEN 1520
570 NEXT L
580 PRINT
590 GOSUB 2030
600 PRINT "STUDY THE GRAPH CAREFULLY. CAN YOU OBSERVE ANY REGULARITIES?"
610 INPUT A$
620 IF A$="YES" THEN 640
630 IF A$="yes" THEN 1540
640 PRINT "WHAT KIND OF RELATIONSHIP EXISTS BETWEEN ACCELERATION AND MASS
(DIRECT"
650 PRINT "OR INVERSE)?"
660 INPUT A$
670 IF A$="INVERSE" THEN 690
680 IF A$="inverse" THEN 2450
690 READ #1, I$
700 FOR I=1 TO 10
710 READ #1, A$
720 PRINT A$
730 NEXT I
740 MAT H=0
750 LET L=1
760 GOSUB 2030
770 PRINT "AAA! VERY INTERESTING."
780 PRINT "THIS GRAPH DOES MAKE THE RELATIONSHIP MORE OBVIOUS. DO YOU SEE W
790 PRINT "I MEAN?"
800 INPUT A$
810 LET L=0
820 PRINT "THE LINEAR GRAPH INDICATES A DIRECT RELATIONSHIP BETWEEN THE TWO
830 PRINT "VARIABLES WE'VE PLOTTED. "
840 PRINT "WRITE AN EQUATION TO FIT THIS GRAPH. DO NOT BOTHER TO CALCULATE T
850 PRINT "SLOPE; INSTEAD REPRESENT THE SLOPE WITH THE CONSTANT 'K'."
860 PRINT "BEGIN THE EQUATION: 1/A= ..."
870 INPUT A$
880 IF A$="1/A=KM" THEN 1040
890 IF A$="1/A=kM" THEN 1040
900 IF A$="1/A=K*M" THEN 1040
910 IF A$="1/A=k*M" THEN 1040
920 IF A$="1/A=KXN" THEN 1040
930 IF A$="1/A=K>N" THEN 1040
940 IF A$="1/A=kXN" THEN 1040
950 IF A$="1/A=kXN" THEN 1040
960 IF A$="1/A=MK" THEN 1040
970 IF A$="1/A=mK" THEN 1040
980 IF A$="1/A=M/K" THEN 1040
990 IF A$="1/A=MxK" THEN 1040
1000 IF A$="1/A=MxK" THEN 1040
1010 IF A$="1/A=MxK" THEN 1040
1020 IF A$="1/A=MxK" THEN 1040
1030 IF A$="1/A=MxK" THEN 2310

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1040 LET L=0
1050 READ #1,25
1060 FOR I=1 TO 8
1070 READ #1;A$
1080 PRINT A$
1090 NEXT I
1100 LET E=4+B/75
1110 PRINT "MASS OF ROCK AND CART (TO THE NEAREST 10TH BRICK)?"
1120 LET L=0
1130 INPUT D
1140 LET F=INT(D+.5)
1150 IF F=INT(E+.5) THEN 1570
1160 PRINT "OK; THE MASS OF ROCK AND CART IS:";E;" BRICKS."
1170 PRINT "WHAT IS THE MASS OF THE ROCK ALONE?"
1180 LET L=0
1190 INPUT F
1200 IF F=0-1 THEN 1220
1210 IF INT(F+.5)≠INT(E-.5) THEN 1680
1220 READ #1,33
1230 FOR I=1 TO 6
1240 READ #1;A$
1250 PRINT A$
1260 NEXT I
1270 LET L=0
1280 PRINT "NOW TRY THIS PROBLEM:"
1290 PRINT "A CAR HAS A MAXIMUM ACCELERATION OF 8 M/SEC/SEC. IF THE CAR TOWS"
1300 PRINT "ANOTHER CAR OF IDENTICAL MASS AND DESIGN, WHAT WILL BE THE MAXIMUM"
1310 PRINT "ACCEL. IN M/SEC/SEC?"
1320 INPUT D
1330 IF D=4 THEN 1800
1340 PRINT "GOOD! NOW HERE'S ANOTHER PROBLEM:"
1350 PRINT "MASS A ACCELERATES AT 30 FT/SEC/SEC AND MASS B ACCELERATES AT"
1360 PRINT "20 FT/SEC/SEC WHEN IDENTICAL FORCES ARE APPLIED."
1370 PRINT "WHAT IS THE RATIO: MASS A/MASS B?"
1380 INPUT A$
1390 IF A$=".25" THEN 1420
1400 IF A$="1/4" THEN 1420
1410 IF A$="1:4" THEN 1910
1420 PRINT "CORRECT!"
1430 PRINT "YOU HAVE NOW COMPLETED THIS SIMULATED EXPERIMENT. PERHAPS YOU WILL"
1440 PRINT "BE"
1450 PRINT "ABLE TO PURSUE THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB. "
1460 PRINT "AFTER YOU'VE SIGNED OFF THE TERMINAL ROLL OUT SEVERAL EXTRA INCHES"
1470 PRINT "OF"
1480 PRINT "PAPER. ON IT LIST THE SOURCES OF EXPERIMENTAL ERROR AS YOU ENVISION"
1490 PRINT "THEM AND STATE THE MAJOR CONCLUSIONS YOU CAN DRAW FROM THE"
1500 PRINT "EXPERIMENT."
1510 PRINT "INCLUDE THIS PAPER IN YOUR PHYSICS NOTEBOOK."
1520 PRINT "AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM LOOP 'FORCE"
1530 PRINT "3'"
1540 PRINT "MOTION IV' AND RUN 'FORCED'."
1550 GOTO 2830
1560 PRINT "YOU DIDN'T TYPE 'PLOT' OR 'RUN'. AGAIN, WHICH SHOULD WE DO?"
1570 GOTO 520
1580 PRINT "LOOK AT THE GRAPH AGAIN. THE PLOTTED POINTS SHOW THAT AS MASS"
1590 PRINT "INCREASES"

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1550 PRINT "ACCELERATION DECREASES; THE PLOT FORMS A SMOOTH CURVE."
1560 GOTO 640
1570 IF L>1 THEN 1640
1580 LET L=L+1
1590 PRINT "SORRY, YOU'RE WRONG. AN EASY WAY TO DETERMINE THE TOTAL MASS IS  
GO"
1600 PRINT "BACK TO THE FIRST GRAPH OF A V. M AND READ THE MASS DIRECTLY FROM  
1610 PRINT "THE GRAPH FOR AN ACCELERATION OF 15.0CM/SEC/SEC. ANSWER THE  
QUESTION"
1620 PRINT "AGAIN."
1630 GOTO 1130
1640 PRINT "WRONG AGAIN. THE ANSWER IS : "E;" BRICKS. IF YOU DON'T UNDERSTAND  
1650 PRINT "DISCUSS THIS WITH YOUR TEACHER AS SOON AS POSSIBLE. NOW WHAT IS  
MASS"
1660 PRINT "OF THE ROCK ALONE?"
1670 GOTO 1190
1680 IF L>1 THEN 1760
1690 LET L=L+1
1700 READ #1, S3
1710 FOR I=1 TO 5
1720 READ #1, A$
1730 PRINT A$
1740 NEXT I
1750 GOTO 1190
1760 PRINT "NO. THE MASS OF THE ROCK IS: "E-1;" BRICKS. YOU NEED ASSISTANCE  
1770 PRINT "INTERPRETING THE GRAPH."
1780 PRINT "CONSULT WITH YOUR TEACHER BEFORE CONTINUING THIS PROGRAM."
1790 GOTO 2330
1800 IF L>1 THEN 1850
1810 LET L=L+1
1820 PRINT "INCORRECT. REMEMBER, ACCEL. IS INVERSELY PROPORTIONAL TO MASS.  
TWICE"
1830 PRINT "THE MASS IS PRESENT IN THE 2ND ACCELERATION. ANSWER THE QUESTION  
AGAIN."
1840 GOTO 1320
1850 READ #1, S3
1860 FOR I=1 TO 4
1870 READ #1, A$
1880 PRINT A$
1890 NEXT I
1900 GOTO 1350
1910 IF L>2 THEN 2000
1920 LET L=L+1
1930 READ #1, S2
1940 FOR I=1 TO 2
1950 READ #1, A$
1960 PRINT A$
1970 NEXT I
1980 PRINT "TRY THE QUESTION AGAIN."
1990 GOTO 1370
2000 PRINT "THE ACCELERATION RATIO IS THE INVERSE OF THE MASS RATIO OR 1/4  
2010 PRINT "YOU NEED FURTHER ASSISTANCE IN UNDERSTANDING THIS CONCEPT."
2020 GOTO 1790
2030 FOR Y=12 TO 1 STEP -1
2040 READ #1, A$
2050 PRINT A$;

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2610 PRINT "DON'T USE MORE THAN 10 BRICKS. SO, AGAIN --"
2620 GOTO 490
2630 PRINT "THE UNSTRETCHED RUBBER LOOP IS ALMOST 50 CM LONG WHEN WE STRETCH
THIS"
2640 PRINT "LOOP LESS THAN 50CM WE'RE NOT APPLYING A SIGNIFICANT FORCE TO TH
2650 PRINT "CART. SO, AGAIN--"
2660 GOTO 260
2670 PRINT "WE'RE STRETCHING THE LOOP WITH A METER STICK WHICH IS 100CM LONG
YOU"
2680 PRINT "CAN'T APPLY A CONSTANT FORCE ACCURATELY IF THE STRETCH EXCEEDS"
2690 PRINT "100CM. SO, AGAIN --"
2700 GOTO 260
2710 PRINT " THIS PROGRAM IS THIRD IN A SERIES. SINCE THE CONCEPTS DEVELOPED
2720 PRINT "ARE SEQUENTIAL, YOU SHOULD BEGIN BY VIEWING THE FILM LOOP 'FORCE
2730 PRINT "MOTION I' AND THEN RUN 'FORCEA'."
2740 GOTO 2830
2750 IF L=0 THEN 2810
2760 LET L=L+1
2770 PRINT "YOU SHOULD KNOW THE CORRECT ANSWER TO THIS QUESTION IF YOU'VE BE
2780 PRINT "THROUGH FORCEB. I'LL GIVE YOU ONE MORE CHANCE TO TYPE IT"
2790 PRINT "PROPERLY."
2800 GOTO 160
2810 PRINT "RUN THE PROGRAM 'FORCEB' BEFORE CONTINUING."
2820 GOTO 2830
2830 PRINT "TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY."
2840 END

```

lunf3

1

RIGHT. NOW TO STUDY HOW ACCELERATION VARIES WHEN THE OBJECT'S
2
MASS IS CHANGED WE'LL TRY TO HOLD ALL OTHER VARIABLES CON-
3
STANT. WE'LL APPLY THE SAME FORCE TO THE CART IN ALL RUNS BY
4
KEEPING ONE LOOP OF RUBBER STRETCHED A CONSTANT LENGTH. (WE
5
CAN STRETCH OUR LOOP BETWEEN 50 AND 100CM.)
6

WE CAN VARY THE CART'S MASS BY USING DIFFERENT NUMBERS OF
7
IDENTICAL BRICKS FOR A LOAD. THE MASS OF THE EMPTY CART
8
WE'LL USE HAS BEEN ADJUSTED TO EQUAL THE MASS OF ONE BRICK.
9

YOU SPECIFY THE NUMBER OF BRICKS YOU'LL USE FOR A LOAD IN
10
EACH TRIAL AND MAKE THE SIMULATED RUN. THEN I'LL DETERMINE
11
ACCELERATION FROM THE TICKER TAPE AND PLOT A GRAPH OF
12
ACCELERATION V. MASS. REMEMBER, THE MASS YOU'RE ACCELERATING
13
IS ONE BRICK LARGER THAN THE LOAD YOU SPECIFY SINCE THE CART
14
HAS A MASS OF 1 BRICK.
15

RIGHT! AS THE CART'S MASS GETS LARGER THE ACCELERATION GETS
16
SMALLER UNDER THE INFLUENCE OF A CONSTANT FORCE.
17

OUR NEXT TASK IS TO FIND AN ALGEBRAIC EXPRESSION FOR THE
18
RELATIONSHIP BETWEEN ACCELERATION AND MASS. A STUDY OF OUR
19
GRAPH SUGGESTS THAT IT MIGHT BE A 1ST POWER INVERSE RELATION-
20
SHIP. THAT IS: ACCEL. IS DIRECTLY PROPORTIONAL TO 1/MASS.
21
OR MASS IS DIRECTLY PROPORTIONAL TO 1/ACCELERATION. TO CHECK
22
OUT THIS PREDICTION I WILL PLOT A NEW GRAPH OF 1/A VERSUS
23
MASS FOR EACH OF OUR TRIALS USING THE DATA WE COLLECTED.
24

HERE'S THE NEW GRAPH:

25

RIGHT! THERE IS A DIRECT RELATIONSHIP BETWEEN $1/A$ AND MASS;

26

K COULD OF COURSE BE REPLACED BY THE NUMERICAL VALUE FOR THE
27
SLOPE OF THE LINE.

28

HERE IS A PROBLEM FOR YOU TO TRY USING YOUR GRAPH AND THE

29

SIMULATED APPARATUS: A ROCK OF UNKNOWN MASS IS PLACED ON OUR
30
UNLOADED CART. YOU MAKE A RUN WITH IT APPLYING THE SAME FORCE

31

AS YOU DID IN THE OTHER RUNS. MY ANALYSIS OF THE TAPE INDICATES

32

AN ACCELERATION OF 15.00 cm/sec/sec . WHAT IS THE TOTAL

33

GOOD! THIS IS ONE METHOD WHICH CAN BE USED TO DETERMINE THE

34

INERTIAL MASS OF AN OBJECT.

35

TO SUMMARIZE, WE CAN SEE FROM THE GRAPHS OF OUR DATA THAT

36

THE ACCELERATION OF AN OBJECT IS INVERSELY PROPORTIONAL TO

37

ITS INERTIAL MASS WHEN A CONSTANT FORCE IS APPLIED, AND

38

THE EQUATION YOU WROTE FOR THE RELATIONSHIP IS: $1/A = KM$.

39

WRONG. WHEN 2 VARIABLES ARE DIRECTLY RELATED, ONE INCREASES

40

AS THE OTHER INCREASES. LOOK AT YOUR GRAPH AGAIN. IT SHOWS

41

THAT THE ACCELERATION BECAME SMALLER AS THE MASS INCREASED.

42

THIS MEANS THAT THE VARIABLES ARE INVERSELY RELATED. SO

43

WRONG. THE GRAPH CAN BE REPRESENTED BY A STRAIGHT LINE PASS-

44

ING THROUGH THE ORIGIN. FROM YOUR WORK IN ALGEBRA YOU KNOW

45

THE EQUATION FOR A STRAIGHT LINE. ($Y = MX + B$ WHERE M IS THE

46

SLOPE AND B THE X-INTERCEPT.) IN THIS CASE WE'RE PLOTTING $1/A$

47

ON THE VERTICAL AXIS AND MASS ON THE HORIZONTAL AXIS. THE

48
MAY'S INTERCEPT IS 0. TRY THE QUESTION AGAIN.
49

50
NO. THE EQUATION SHOULD BE EXPRESSED AS: $1/A=KM$. IF YOU
51
DON'T UNDERSTAND WHY DISCUSS THIS WITH YOUR TEACHER AS
52
SOON AS POSSIBLE. NOW HERE'S THE QUESTION ONCE MORE. TYPE
53
IN THE EQUATION I'VE STATED.

54
NO, YOU'RE WRONG. REMEMBER THAT WE ACCELERATED THE ROCK AND
55
THE CART AND WE HAVE PLOTTED THE TOTAL MASS. TO FIND THE
56
MASS OF THE ROCK WE MUST SUBTRACT THE CART'S MASS (1 BRICK)
57
FROM THE TOTAL MASS DETERMINED IN THE LAST QUESTION.

58
TRY THE QUESTION AGAIN.

59
WRONG. WITH TWICE THE MASS THE CONSTANT FORCE CAUSES $1/2$
60
THE ORIGINAL ACCELERATION OR $4M/SEC/SEC$. IF YOU DON'T
61
UNDERSTAND DISCUSS THIS WITH YOUR TEACHER AS SOON AS
62
POSSIBLE. NOW HERE'S ANOTHER PROBLEM.

63
NO. THE PROBLEM ASKS FOR THE RATIO OF MASS A/MASS B. THIS IS
64
EQUIVALENT TO $ACCEL.B/ACCEL.A$ DUE TO THE INVERSE RELATIONSHIP.

list
FORCED

```
10 FILES LUNFA
20 DIM ASC(65)
30 READ #1,1
40 FOR I=1 TO 4
50 READ #1;AS
60 PRINT AS
70 NEXT I
80 INPUT AS
90 IF AS="yes" THEN 110
100 IF AS="YES" THEN 2870
110 READ #1,5
120 FOR I=1 TO 6
130 READ #1;AS
140 PRINT AS
150 NEXT I
160 LET L=0
170 INPUT AS
180 IF AS="inverse" THEN 200
190 IF AS="INVERSE" THEN 2930
200 READ #1,11
210 FOR I=1 TO 12
220 READ #1;AS
230 PRINT AS
240 NEXT I
250 PRINT "I'VE JUST TYPED A LOT OF INFORMATION HERE. READ IT CAREFULLY AND TYPE"
260 PRINT "'GO' WHEN YOU WANT ME TO CONTINUE."
```

```

270 INPUT AS
280 IF AS="GO" THEN 330
290 IF AS="go" THEN 330
300 PRINT "YOU DIDN'T TYPE 'GO'. I CAN'T CONTINUE UNTIL YOU DO."
310 PRINT "TYPE 'GO' AND WE'LL CONTINUE."
320 GOTO 270
330 PRINT "IN THE EQUATION  $K$  IS A CONSTANT OF PROPORTIONALITY AND ITS"
340 PRINT "NUMERICAL VALUE DEPENDS UPON THE UNITS USED TO MEASURE FORCE,"
350 READ #1,23
360 FOR I=1 TO 18
370 READ #1;AS
380 PRINT AS
390 NEXT I
400 LET L=0
410 PRINT "WHAT IS THE NET FORCE (IN NEWTONS) ACTING ON THE SPACESHIP?"
420 INPUT AS
430 IF AS="1200" THEN 450
440 IF AS="1,200" THEN 1660
450 PRINT "CORRECT! NOW HERE'S A SLIGHT VARIATION OF THE SAME PROBLEM:"
460 PRINT "AN 80KG ASTRONAUT IN EQUILIBRIUM OUTSIDE HIS SPACESHIP RECEIVES A"
470 PRINT "40N FORCE FROM A PROPULSION JET ATTACHED TO HIM."
480 LET L=0
490 PRINT "WHAT ACCEL. (IN M/SEC/SEC) DOES HE EXPERIENCE?"
500 INPUT AS
510 IF AS=".5" THEN 530
520 IF AS="1/2" THEN 1620
530 READ #1,41
540 FOR I=1 TO 2
550 READ #1;AS
560 PRINT AS
570 NEXT I
580 PRINT "TRY THIS PROBLEM AGAIN WHICH INVOLVES NEGATIVE ACCELERATION: A 2000"
590 READ #1,43
600 FOR I=1 TO 4
610 READ #1;AS
620 PRINT AS
630 NEXT I
640 LET L=0
650 INPUT AS
660 IF AS="4000" THEN 700
670 IF AS="4,000" THEN 700
680 IF AS="-4000" THEN 700
690 IF AS="-4,000" THEN 1680
700 LET L=0
710 READ #1,47
720 FOR I=1 TO 6
730 READ #1;AS
740 PRINT AS
750 NEXT I
760 PRINT "WHAT IS THE FRICTIONAL FORCE ACTING ON THE STOVE IN N?"
770 INPUT AS
780 IF AS="250" THEN 800
790 IF AS="-250" THEN 2000
800 LET L=0
810 READ #1,53

```

```

820 FOR I=1 TO 4
830 READ #1;A$
840 PRINT A$
850 NEXT I
860 INPUT D
870 IF D>1.5 THEN 2100
880 READ #1,57
890 FOR I=1 TO 4
900 READ #1;A$
910 PRINT A$
920 NEXT I
930 PRINT TAB(9);"10+"
940 PRINT "V";TAB(11);"+"
950 PRINT "E";TAB(10);"8+";TAB(27);"X   X   X"
960 PRINT "L";TAB(11);"+";TAB(23);"X"
970 PRINT "O";TAB(10);"6+           X";TAB(37);"X"
980 PRINT "C (M/SEC)  +   X"
990 PRINT "I";TAB(10);"4X";TAB(39);"X"
1000 PRINT "T";TAB(11);"+";TAB(41);"X"
1010 PRINT "Y";TAB(10);"2+";TAB(43);"X"
1020 PRINT TAB(11);"+";TAB(45);"X"
1030 PRINT TAB(10);"0+ + + + + + + + + + + + + + + X + +"
1040 PRINT TAB(11);"0   2   4   6   8   10  12  14  16  18  20"
1050 PRINT TAB(26);"TIME (SEC)"
1060 LET L=0
1070 READ #1,61
1080 FOR I=1 TO 2
1090 READ #1;A$
1100 PRINT A$
1110 NEXT I
1120 PRINT "1. THE NET FORCE ACTING ON THE OBJECT WAS 0 AT: (A) 0 SEC; (B)"
1130 PRINT "4SEC; (C) 10SEC; (D) 13SEC; (E) 16SEC; (F) NONE OF THE ABOVE"
1140 INPUT A$
1150 IF A$="C" THEN 1170
1160 IF A$="D" THEN 2260
1170 READ #1,64
1180 FOR I=1 TO 4
1190 READ #1;A$
1200 PRINT A$
1210 NEXT I
1220 INPUT A$
1230 IF A$="D" THEN 1250
1240 IF A$="D" THEN 2360
1250 PRINT "GOOD!"
1260 PRINT "3. THE NET FORCE WAS CONSTANT BETWEEN: (A) 6-9SEC; (B) 9-13SEC;"
1270 PRINT "(C) 13-15SEC; (D) 15-18SEC; (E) NONE OF THE ABOVE"
1280 INPUT A$
1290 IF A$="D" THEN 1310
1300 IF A$="D" THEN 2450
1310 PRINT "CORRECT!"
1320 LET L=0
1330 PRINT "4. WHAT WAS THE ACCEL. OF THE OBJECT (IN M/SEC/SEC) AT 6 SEC?"
1340 INPUT A$
1350 IF A$=".5" THEN 1370
1360 IF A$="1/2" THEN 2540

```

```

1370 PRINT "FINE!"
1380 PRINT "5. DETERMINE THE NET FORCE (IN N) AT 6 SEC. (OBJECT HAS MASS OF 10KG)"
1390 INPUT D
1400 IF D#5 THEN 2630
1410 PRINT "VERY NICE."
1420 PRINT "YOU'LL NOTICE ON THE GRAPH THAT THIS CONSTANT FORCE OF 5N WAS APPLIED"
1430 PRINT "FROM 0SEC THROUGH 8 SEC. NOW, THE FINAL PROBLEM:"
1440 PRINT "6. DETERMINE THE FORCE (IN N) ACTING AT 13 SEC."
1450 LET L=0
1460 INPUT D
1470 IF ABS(D)#20 THEN 2700
1480 READ #1,68
1490 FOR I=1 TO 17
1500 READ #1;AS
1510 PRINT AS
1520 NEXT I
1530 LET L=0
1540 PRINT "BEGIN THE EQUATION: F= ... AND DO NOT INCLUDE A MULTIPLICATION SIGN."
1550 INPUT AS
1560 IF AS="F=MA" THEN 1640
1570 IF AS="f=ma" THEN 1640
1580 IF AS="F=KMA" THEN 1640
1590 IF AS="f=Kms" THEN 1640
1600 IF AS="A=F/M" THEN 1640
1610 IF AS="a=f/m" THEN 1640
1620 IF AS="a=Kf/m" THEN 1640
1630 IF AS="A=KF/M" THEN 2780
1640 PRINT "AUF WIEDERSEHEN"
1650 GOTO 3030
1660 IF L>1 THEN 1740
1670 LET L=L+1
1680 READ #1,91
1690 FOR I=1 TO 3
1700 READ #1;AS
1710 PRINT AS
1720 NEXT I
1730 GOTO 410
1740 READ #1,94
1750 FOR I=1 TO 3
1760 READ #1;AS
1770 PRINT AS
1780 NEXT I
1790 GOTO 460
1800 IF L>1 THEN 1840
1810 LET L=L+1
1820 PRINT "NO. SINCE F=MA, A=F/M. TRY THE PROBLEM AGAIN:"
1830 GOTO 490
1840 PRINT "40N/80KG=1/2M/SEC/SEC."
1850 PRINT "YOU NEED FURTHER ASSISTANCE IN UNDERSTANDING THIS CONCEPT. CONSULT"
1860 PRINT "WITH YOUR TEACHER BEFORE CONTINUING THIS PROGRAM."
1870 GOTO 3030
1880 LET L=L+1
1890 IF L=3 THEN 1940
1900 IF L>3 THEN 1850
1910 PRINT "WRONG ANSWER. FIRST FIND THE CAR'S ACCEL. (IT LOSES 30M/SEC IN 15 SEC.)"
1920 PRINT "THEN: F=MA. CHECK THE PROBLEM AND TYPE IN YOUR NEW ANSWER."

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```

1930 GOTO 650
1940 READ #1,97
1950 FOR I=1 TO 4
1960 READ #1;AS
1970 PRINT AS
1980 NEXT I
1990 GOTO 650
2000 IF L>1 THEN 2080
2010 LET L=L+1
2020 READ #1,101
2030 FOR I=1 TO 5
2040 READ #1;AS
2050 PRINT AS
2060 NEXT I
2070 GOTO 760
2080 PRINT "NO. THE FRICTIONAL FORCE IS 250N."
2090 GOTO 1850
2100 LET L=L+1
2110 IF L=3 THEN 2190
2120 IF L>3 THEN 1850
2130 READ #1,106
2140 FOR I=1 TO 4
2150 READ #1;AS
2160 PRINT AS
2170 NEXT I
2180 GOTO 860
2190 PRINT "NO. MASS A=F/A=12/2=6KG; MASS B =12/6=2KG."
2200 READ #1,110
2210 FOR I=1 TO 4
2220 READ #1;AS
2230 PRINT AS
2240 NEXT I
2250 GOTO 860
2260 IF L>1 THEN 2320
2270 LET L=L+1
2280 PRINT "WRONG. SINCE F=MA, THE FORCE = 0 WHERE THE ACCEL. = 0."
2290 PRINT "THE ACCEL. = 0 WHERE THE VELOCITY IS NOT CHANGING. TRY THE PROBLEM"
2300 PRINT "AGAIN AND TYPE IN THE CORRECT ANSWER"
2310 GOTO 1140
2320 PRINT "NO. THE ACCEL. IS 0 BETWEEN 8 AND 12 SEC. IF YOU DON'T UNDERSTAND"
2330 PRINT "DISCUSS THIS WITH YOUR TEACHER AS SOON AS POSSIBLE. NOW, TYPE IN THE"
2340 PRINT "LETTER OF THE CORRECT RESPONSE."
2350 GOTO 1140
2360 IF L>2 THEN 2430
2370 LET L=L+1
2380 PRINT "WRONG. SINCE F=MA, THE FORCE IS GREATEST WHERE THE ACCEL. IS GREATEST."
2390 PRINT "REMEMBER THAT THE ACCEL. AT ANY POINT IS THE SLOPE OF THE V VERSUS T"
2400 PRINT "GRAPH. FIND THE PLACE WHERE THE VELOCITY IS CHANGING AT THE GREATEST"
2410 PRINT "RATE. NOW TYPE IN THE CORRECT ANSWER."
2420 GOTO 1220
2430 PRINT "NO; THE FORCE IS GREATEST AT 13 SEC."
2440 GOTO 1850
2450 IF L>1 THEN 2520
2460 LET L=L+1
2470 PRINT "INCORRECT. THE FORCE IS CONSTANT WHERE THE ACCEL. IS CONSTANT."
2480 PRINT "REMEMBER THAT THE ACCEL. AT ANY POINT IS THE SLOPE OF THE V VERSUS T"

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2490 PRINT "GRAPH. FIND THE LISTED TIME INTERVAL IN WHICH VELOCITY CHANGES AT A"
2500 PRINT "CONSTANT RATE, AND TYPE IN THE CORRECT ANSWER."
2510 GOTO 1280
2520 PRINT "NO. THE CORRECT CHOICE WAS 15-18SEC."
2530 PRINT "NO. THE CORRECT CHOICE IS 15-18 SEC."
2540 IF L>1 THEN 2600
2550 LET L=L+1
2560 PRINT "WRONG. ACCEL. AT ANY POINT IS THE SLOPE OF THE V VERSUS T GRAPH."
2570 PRINT "A=CHANGE IN V/CHANGE IN T. CHECK YOUR CALCULATION AND TYPE IN THE"
2580 PRINT "CORRECT ANSWER."
2590 GOTO 1340
2600 PRINT "NO. THE SLOPE IS .5M/SEC/SEC. LOOK AT THE GRAPH AND SEE IF YOU AGREE."
2610 PRINT "THEN TRY THIS QUESTION:"
2620 GOTO 1380
2630 IF L>2 THEN 2680
2640 LET L=L+1
2650 PRINT "WRONG. F=MA. MULTIPLY THE MASS(10KG) BY THE ACCEL. CALCULATED IN THE"
2660 PRINT "LAST PROBLEM. CHECK YOUR CALCULATIONS AND TYPE IN THE CORRECT ANSWER."
2670 GOTO 1390
2680 PRINT "NO. F=MA=10X.5=5N."
2690 GOTO 1850
2700 IF L>1 THEN 2760
2710 LET L=L+1
2720 PRINT "INCORRECT. FIND THE ACCEL. AS YOU DID IN PROBLEM #4 ABOVE"
2730 PRINT "(CHANGE IN V/CHANGE IN T). THEN F=MA. CHECK YOUR CALCULATIONS AGAIN"
2740 PRINT "AND TYPE IN THE CORRECT FORCE."
2750 GOTO 1460
2760 PRINT "NO, THE ANSWER IS: -20N."
2770 GOTO 1850
2780 IF L>0 THEN 2840
2790 LET L=L+1
2800 PRINT "YOU MUST BE KIDDING! I'VE SPENT ALL THIS TIME WITH YOU AND YOU CAN'T"
2810 PRINT " SAY 'F=MA'?"
2820 PRINT "OH, THIS IS AWFUL! TRY TYPING THE EQUATION AGAIN."
2830 GOTO 1550
2840 PRINT "NOW I'LL BELIEVE YOU'RE KIDDING. I'LL TYPE IT FOR YOU:"
2850 PRINT "F=MA"
2860 GOTO 1640
2870 READ #1,35
2880 FOR I=1 TO 3
2890 READ #1;A5
2900 PRINT A5
2910 NEXT I
2920 GOTO 3030
2930 IF L#0 THEN 3010
2940 LET L=L+1
2950 READ #1,88
2960 FOR I=1 TO 3
2970 READ #1;A5
2980 PRINT A5
2990 NEXT I
3000 GOTO 170
3010 PRINT "RUN 'FORCEC' BEFORE CONTINUING."
3020 GOTO 3030
3030 PRINT "TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY."
3040 END

```

WHAT FILE IS TO BE LISTED?

?1unf4

STARTING RECORD NUMBER?

?1

1

HI! IN THIS FINAL PROGRAM OF THE SERIES WE WILL DISCUSS WHAT

2

WE'VE LEARNED ABOUT FORCE AND MOTION AND INTRODUCE A SYSTEM

3

OF UNITS IN COMMON USE. HAVE YOU COMPLETED 'FORCEC' AND THEN

4

VIEWS FILM LOOP 'FORCE & MOTION IV'?

5

IN THE FIRST EXPERIMENT WE OBSERVED THAT A CONSTANT FORCE

6

CAUSES A BODY TO UNDERGO A CONSTANT ACCELERATION. IN THE

7

2ND EXPERIMENT WE OBSERVED THAT ACCELERATION WAS DIRECTLY

8

PROPORTIONAL TO THE NET FORCE. IN THE 3RD EXPERIMENT WE

9

OBSERVED WHAT KIND OF RELATIONSHIP BETWEEN ACCELERATION AND

10

MASS?

11

CORRECT! WE MAY WRITE THIS LAST STATEMENT AS:

12

1) M IS DIRECTLY PROPORTIONAL TO $1/A$ OR

13

2) A IS DIRECTLY PROPORTIONAL TO $1/M$

14

FROM THE RESULTS OF EXPERIMENT 2 WE CAN WRITE:

15

3) A IS DIRECTLY PROPORTIONAL TO F

16

STATEMENTS (2) & (3) CAN BE COMBINED AND WRITTEN AS:

17

A IS DIRECTLY PROPORTIONAL TO F/M

18

AN EQUIVALENT STATEMENT IS:

19

MA IS DIRECTLY PROPORTIONAL TO F

20
OR: F IS DIRECTLY PROPORTIONAL TO MA
21

IN EQUATION FORM:

22
F=KMA
23
MASS, AND ACCELERATION. IT WOULD HAVE A SPECIFIC VALUE IF WE
24
CONTINUED TO MEASURE FORCE IN 'POUNDS' AND MASS IN 'BRICKS'.
25
THE UNITS WE USED HAPPENED TO BE CONVENIENT FOR US, BUT
26
THEY ARE NOT IN COMMON USE IN THE WORLD. THE EQUATION, OFTEN
27
REFERRED TO AS NEWTON'S 2ND LAW, IS PERHAPS THE MOST FUNDA-
28
MENTAL EQUATION IN CLASSICAL MECHANICS, AND THE UNIT OF FORCE
29
COMMONLY USED IS DEFINED SO THAT K IN THE EQUATION = 1.
30

IN SCIENTIFIC WORK A VERY COMMON UNIT OF MASS IN USE TODAY
31
IS THE KILOGRAM (KG). THE BASIC UNIT OF FORCE WILL CAUSE A
32
MASS OF 1 KILOGRAM TO ACCELERATE AT 1M/SEC/SEC. THIS UNIT OF
33
FORCE IS CALLED THE NEWTON (N). IN OTHER WORDS A FORCE OF 1N
34
WILL CAUSE A MASS OF 1KG TO ACCELERATE 1M/SEC/SEC. USING THESE
35
UNITS THE EQUATION IS WRITTEN:
36

F=MA
37

1N=1KG M/SEC/SEC
38

TRY THE FOLLOWING PROBLEM USING THE MKS (METER, KILOGRAM,
39
SECOND) SYSTEM OF UNITS. A 600KG SPACESHIP IS PROPELLED BY
40
A ROCKET ENGINE. ITS ACCELERATION IS 2M/SEC/SEC.
41

RIGHT! IT IS IMPORTANT TO POINT OUT AS I DID IN EXP. 2 THAT F
42
REPRESENTS THE VECTOR SUM OF ALL FORCES ACTING ON THE OBJECT.
43
A 1000 KG CAR IS TRAVELLING AT A SPEED OF 30M/SEC WHEN THE BRAKES

44
 ARE APPLIED. THE CAR STOPS IN 15 SEC. IF WE ASSUME A CON-
 45
 STANT ACCELERATION, WHAT WAS THE FORCE (IN N) APPLIED BY THE
 46
 BRAKES?
 47

GOOD! THE NEGATIVE BRAKING FORCE PRODUCED A NEGATIVE ACCEL.
 48
 IF THE VECTOR SUM OF THE FORCES ON A OBJECT = 0, THEN THE
 49
 OBJECT WILL UNDERGO 0 ACCELERATION. IN OTHER WORDS ITS
 50
 VELOCITY WILL NOT CHANGE. HERE'S A PROBLEM ON THE SUBJECT:
 51
 TO PUSH MY STOVE ACROSS MY KITCHEN FLOOR AT A CONSTANT
 52
 SPEED OF 1M/SEC, I MUST APPLY A FORCE OF 250N.
 53

SURE! NOW TRY THIS PROBLEM: A FORCE OF 12N GIVES MASS A
 54
 AN ACCEL. OF 2M/SEC/SEC AND MASS B AN ACCEL. OF 6M/SEC/SEC.
 55
 WHAT IS THE ACCEL, (IN M/SEC/SEC) WHEN THE TWO ARE FASTENED
 56
 TOGETHER AND THE SAME FORCE IS APPLIED?
 57

GOOD!

58
 THE LAST FEW QUESTIONS DEAL WITH THE GRAPH PRINTED BELOW
 59
 WHICH SHOWS THE VELOCITY OF A 10KG OBJECT ALONG A STRAIGHT
 60
 PATH.
 61

IN THE NEXT 3 QUESTIONS TYPE IN THE LETTER OF THE BEST
 62
 RESPONSE:
 63

64

CORRECT!

65

2. THE NET FORCE ACTING ON THE OBJECT WAS GREATEST AT:
 66
 (A) 0 SEC; (B) 4 SEC; (C) 10 SEC; (D) 13 SEC; (E) 16 SEC;

67
(F) NONE OF THE ABOVE.
68

OK! IT'S A GOOD IDEA TO WRITE THIS FORCE AS -20N SINCE
69
THE FORCE IS OPPOSITE THE DIRECTION IN WHICH THE OBJECT IS
70
MOVING.
71

THE IDEAS WE'VE BEEN DISCUSSING IN THESE FOUR PROGRAMS ARE
72
FUNDAMENTAL IN CLASSICAL MECHANICS. OUR UNDERSTANDING OF THEM
73
HAS BEEN GREATLY ENHANCED BY THE BRILLIANT INSIGHTS PROVIDED
74
BY GALILEO, NEWTON, AND THEIR SUCCESSORS. THE STORY OF THE WORK
75
OF THESE EARLY SCIENTISTS IS FASCINATING READING.
76
THESE IDEAS PROVIDE A STARTING POINT FOR FURTHER STUDY IN
77
MECHANICS. VERY SOON, FOR EXAMPLE, YOU WILL STUDY FALLING
78
BODIES. WHEN A BODY FALLS THE FORCE CAUSING IT TO ACCELERATE
79
IS ITS WEIGHT...
80

IT HAS BEEN VERY NICE WORKING WITH YOU IN THESE PAST FOUR
81
EXPERIMENTS. PERHAPS WE'LL MEET AGAIN IF SOMEONE WILL WRITE
82
MORE PROGRAMS...?
83

BEFORE WE PART, YOU'LL HAVE TO TYPE IN THE EQUATION REPRE-
84
SENTING NEWTON'S 2ND LAW WHICH WE DEVELOPED IN THIS PROGRAM.
85
THIS PROGRAM IS THE 4TH IN A SERIES. SINCE THE CONCEPTS DEVELOPED
86
ARE SEQUENTIAL YOU SHOULD BEGIN BY VIEWING THE FILM LOOP
87
'FORCE & MOTION 1' AND THEN RUN 'FORCEA'.
88

YOU SHOULD KNOW THE CORRECT ANSWER TO THIS QUESTION IF YOU'VE
89
BEEN THROUGH 'FORCEC'. I'LL GIVE YOU ONE MORE CHANCE TO TYPE
90
IT PROPERLY.

91

WRONG. THE FORCE (IN N) = MASS (KG) X ACCEL (M/SEC/SEC).

92

MULTIPLY THE MASS TIMES THE ACCELERATION TO FIND THE FORCE IN

93

NEWTONS. TRY THE PROBLEM AGAIN.

94

NO. $600\text{KG} \times 2\text{M/SEC/SEC} = 1200\text{N}$. IF YOU DON'T UNDERSTAND

95

DISCUSS THIS WITH YOUR TEACHER AS SOON AS POSSIBLE. NOW HERE'S

96

ANOTHER PROBLEM.

97

NO. THE ACCELERATION IS $30/15 = 2\text{M/SEC/SEC}$. $F=2000 \times 2 = 4000\text{N}$.

98

IF YOU DON'T UNDERSTAND DISCUSS THIS WITH YOUR TEACHER AS

99

SOON AS POSSIBLE. READ THE PROBLEM AGAIN AND ANSWER IT

100

CORRECTLY.

101

INCORRECT. THE STOVE IS TRAVELLING AT A CONSTANT SPEED; THERE

102

IS NO ACCELERATION. THEREFORE THE SUM OF ALL FORCES ON THE

103

STOVE MUST =0. IF 250N IS BEING APPLIED TO PUSH THE STOVE,

104

THERE MUST BE AN EQUAL AND OPPOSITE FORCE DUE TO FRICTION.

105

ANSWER THE PROBLEM AGAIN.

106

SORRY, WRONG ANSWER. YOU CAN FIND MASS A AND MASS B BY

107

USING NEWTON'S 2ND LAW FOR EACH. THE NEW MASS BEING ACCEL.

108

RATED IS THE SUM OF MASS A AND B. USE THE 2ND LAW TO FIND

109

THE NEW ACCELERATION. ANSWER THE QUESTION AGAIN.

110

THE TOTAL MASS = $6+2=8\text{KG}$. THE NEW ACCEL. = $F/M=12/8=1.5$.

111

IF YOU DON'T UNDERSTAND, DISCUSS THIS WITH YOUR TEACHER AS

112

SOON AS POSSIBLE. READ THE PROBLEM AGAIN AND ANSWER IT

113

CORRECTLY.

114

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

NON-COMPUTER SIMULATION AND PROBLEM SHEETS

technical report 1

In this first investigation the experimenters are studying how an object's velocity changes when a constant force is applied. Throughout all the runs of today's experiments the rubber band has been stretched 60 cm. and the force is held constant as you observed in the film loop.

In the first run there were two bricks on the cart, and the experimenters gathered the following data from a careful analysis of the ticker tape pulled by the cart.

<u>TIME</u> (sec)	<u>VELOCITY</u> (cm/sec)
.1	1.6
.2	3.2
.3	4.8
.4	6.4
.5	8.0
.6	9.6
.7	11.2
.8	12.8
.9	14.4
1.0	16.0

To see how the data would differ under the influence of a different load, the experimenters made a second run with four bricks on the cart. The following data was gathered from a careful analysis of the ticker tape made in the run.

<u>TIME</u> (sec)	<u>VELOCITY</u> (cm/sec)
.1	1.0
.2	1.9
.3	2.9
.4	3.8
.5	4.8
.6	5.8
.7	6.8
.8	7.7
.9	8.6
1.0	9.6

To study the data, construct a graph plotting both curves on the same velocity vs. time axes for ease of comparison.

Next, discuss the following questions in your experiment reports:

1. What kind of relationship exists between velocity and time under these conditions?
2. The constant force gave the cart what kind of acceleration? (Remember that the acceleration of an object at any point is the slope of its velocity vs. time graph at that point.)
3. Analyze the graph and determine the acceleration in cm/sec^2 produced by the force in both runs.
4. Was the acceleration greater or smaller when the smaller mass was accelerated?

Next, list the sources of experimental error as you envision them and state the major conclusions you can draw from the experiment.

After you have completed the write-up of the experiment, do the following problem:

If an airplane's engines produce a net force which is constant and which accelerates the plane from 0 to 100 m/sec in 20 sec., what will be the plane's velocity at the end of 40 sec.?

In the first experiment, we observed that a constant force gave our cart a constant acceleration. In this investigation the experimenters are studying how different forces affect the acceleration of an object. As you observed in the film, we can vary the force we apply by using different numbers of rubber loops stretched a constant length.

In this particular experiment the loops were always stretched 60 cm, and the cart was loaded with 2 bricks throughout all the runs. A different value of force was applied in each run, and the corresponding value of acceleration was determined from a careful analysis of the ticker tape pulled by the cart in each run. Here is a table of the data collected in this experiment.

FORCE (loops)	ACCELERATION (cm/sec ²)
1	8
2	24
3	40
4	56
5	72
6	88

To study the data plot a graph of Acceleration vs. Force.

Next, discuss the following questions in your experiment report:

1. What kind of relationship exists between acceleration and force under these conditions?
2. (A) If we extend the graph, what acceleration do we predict for a force of 0 loops?
(B) Is this extrapolation justified?
3. Note that the graph does not pass through the origin. Perhaps a frictional force keeps the cart from accelerating when we apply a small positive force. If this hypothesis is true, determine from the graph the force of friction in the system.
4. Had we used a cart with greater friction than in our experiment, would the intercept on the force axis be to the right or to the left of its present location?

If, the experimenters had plotted the resultant force acting on the cart instead of the applied force, the graph would have passed through the origin. (The resultant force is the applied force minus the force of friction; a graph of the resultant force vs. acceleration represents the relationship for a frictionless cart.) On your graph paper, sketch a dashed line to display the F vs. A relationship if the cart had been frictionless.

Write an equation to fit the dashed line. Use K to represent the slope (don't bother to calculate it).

List the sources of experimental error as you envision them, and state the major conclusions you can draw from the experiment.

After you have completed the write-up of this experiment do the following problems:

1. A spaceship is accelerating in space at 10 m/sec² due to the force provided by one rocket engine. Suddenly two more identical rockets are ignited providing thrust in the same direction as the first. What acceleration does the ship now experience?
2. In 10 sec. an object accelerates from rest to a speed of 300 cm/sec when acted upon by a net force (F). At the end of the 10 sec. interval F becomes one-third its original strength. What is the speed of the object

In the first experiment of this series we observed that a constant force caused a body to have a constant acceleration. In the last experiment we held the mass constant and observed that the acceleration of the cart was directly proportional to the applied force. In this investigation the experimenters are studying how a constant force accelerates different masses. As you observed in the film, we can vary the cart's mass by using different numbers of identical bricks for a load.

In this particular experiment the mass of the empty cart was adjusted to equal the mass of one brick, and a constant force of 50 cm was applied to the cart throughout all runs. A different number of bricks was placed on the cart in each run, and the corresponding value of acceleration was determined from a careful analysis of the ticker tape pulled by the cart in each run. Here is a table of the data collected in this experiment.

TOTAL MASS of Load and Cart (bricks)	ACCELERATION (cm/sec ²)	1/A
2	32.0	.031
3	21.3	.047
5	12.8	.078
7	9.1	.109
9	7.1	.141

To study the data plot a graph of Acceleration vs. Mass.

Next, discuss the kind of relationship which exists between acceleration and mass under these conditions.

Our primary task as physicists is to find an algebraic expression for the relationship between acceleration and mass. A study of the graph you've just constructed suggests that it might be a 1st power inverse relationship, that is: acceleration is directly proportional to 1/mass, or mass is directly proportional to 1/acceleration. To check out, this prediction, plot a new graph of 1/A vs. Mass for each of our trials using the data collected in the experiment.

What kind of relationship exists between the two variables which you've plotted?

Write an equation to fit this graph. Use K to represent the slope (don't bother to calculate it).

Here is a problem for you to try using your graphs and the experimental apparatus: A rock of unknown mass was placed on the unloaded cart. A run was made with it applying the same force as in the other runs. An analysis of the tape indicated an acceleration of 15.0 cm/sec². What was the total mass of rock and cart?

What is the mass of the rock alone? (This method you're using is one means of determining the inertial mass of an object.)

List the sources of experimental error as you envision them, and state the major conclusions you can draw from the experiment.

After you have completed the write-up of this experiment do the following problems:

1. A car has a maximum acceleration of 8 m/sec². If the car tows another car of identical mass and design, what will be the maximum acceleration?

.....
Mass A accelerates at 80 ft/sec² and mass B accelerates at 20 ft/sec² when identical forces are applied. What is the ratio: MassA/MassB?

In this final section of the series, we will discuss what we've learned about force and motion and introduce a system of units in common use. In the first experiment we observed that a constant force causes a body to undergo a constant acceleration. In the second experiment we observed that acceleration was directly proportional to the net force. In the third experiment we observed what mass and acceleration are inversely related when a constant force is applied.

We may write this last statement as:

- 1) M is directly proportional to $1/A$ or
- 2) A is directly proportional to $1/M$

From the results of Experiment 2 we can write:

- 3) A is directly proportional to F

Statements (2) and (3) can be combined and written as:

A is directly proportional to F/M

An equivalent statement is:

MA is directly proportional to F
or: F is directly proportional to MA

In equation form:

$$F = KMA$$

In this equation K is a constant of proportionality and its numerical value depends upon the units used to measure force, mass, and acceleration. It would have a specific value if we continued to measure force in LOOPS and mass in BRICKS. The units we used happened to be convenient for us, but they are not in common use in the world. The equation, often referred to as Newton's 2nd Law, is perhaps the most fundamental equation in classical mechanics, and the unit of force commonly used is defined so that K in the equation equals 1. In scientific work a very common unit of mass in use today is the kilogram (kg). The basic unit of force will cause a mass of 1 kilogram to accelerate at 1 m/sec^2 . This unit of force is called the Newton (N). In other words, a force of 1 Newton will cause a mass of 1 Kilogram to accelerate 1 m/sec^2 . Using these units the equation is written:

$$F = MA$$

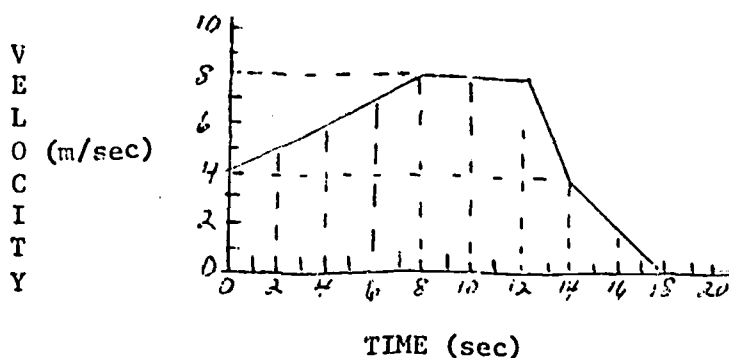
$$1 \text{ N} = 1 \text{ kg m/sec}^2$$

Read the information above carefully. After you understand it, do the following problems.

1. A 600 kg spaceship is propelled by a rocket engine. Its acceleration is 2 m/sec^2 . What is the net force acting on the spaceship?
2. An 80 kg astronaut in equilibrium outside his spaceship receives a 40 Newton force from a propulsion jet attached to him. What acceleration does he experience?
3. A 2000 kg car is travelling at a speed of 30 m/sec when the brakes are applied. The car stops in 15 sec. If we assume a constant acceleration, what was the force applied by the brakes?
4. To push my stove across my kitchen floor at a constant speed of 1 m/sec. I must apply a force of 250 N. What is the frictional force acting on the

5. A force of 12 N gives mass A an acceleration of 2 m/sec^2 and mass B an acceleration of 6 m/sec^2 . What is the acceleration when the two are fastened together and the same force is applied?

The last few questions deal with the graph printed below which shows the velocity of a 10 kg object along a straight path.



6. The net force acting on the object was 0 at: (A) 0 sec; (B) 4 sec; (C) 10 sec; (D) 13 sec; (E) 16 sec; (F) None of the above.
7. The net force acting on the object was greatest at: (A) 0 sec; (B) 4 sec; (C) 10 sec; (D) 13 sec; (E) 16 sec; (F) None of the above.
8. The net force was constant between: (A) 6-9 sec; (B) 9-13 sec; (C) 13-15 sec; (D) 15-18 sec; (E) None of the above.
9. What was the acceleration of the object at 6 sec?
10. Determine the net force at 6 sec. (The object has a mass of 10 kg.)
11. Determine the net force acting on the object at 13 sec.

The ideas we've been discussing in these four "experiments" are fundamental in classical mechanics. Our understanding of them has been greatly enhanced by the brilliant insights provided by Galileo, Newton, and their successors. The story of the work of these early scientists is fascinating reading.

These ideas provide a starting point for further study in mechanics. Very soon, for example, you will apply them in the study of falling bodies. When an object falls the force causing it to accelerate is its own weight...

$$F = MA$$

Answers to some of the above questions are:

1. 1200 N
2. $.5 \text{ m/sec}^2$
3. 4000 N
4. 250 N
5. 1.5 m/sec^2

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

ACQUISITION AND USE OF MATERIALS

technical report 1

Acquisition and Use of Materials

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